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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 11 May 1955, the Chair being taken by the President, Lt.-Col. S. J. M. Auld, O.B.E., M.C., D.Sc.

The General Secretary read the minutes of the previous meeting, which were confirmed and signed as a correct record. He also announced the names of members elected since the previous meeting, and gave notice of the date of the next meeting.

The Chairman introduced Messrs E. H. Walker, R. M. Eltringham, and A. Puttick, who presented the following paper in summary.

EVAPORATION LOSSES FROM PETROL STORAGE TANKS IN THE UNITED KINGDOM—A PRACTICAL SURVEY*

By E. H. WALKER,† R. M. ELTRINGHAM,† and A. PUTTICK†

SUMMARY

This paper presents thermal breathing loss measurements obtained from both standing and working tanks located in a number of places in the U.K. A method is given by which the results can be correlated and used to predict thermal breathing losses from readily available data. The results emphasize the importance of maintaining the tank and its fittings in a vapour-tight condition. The mathematical basis of the survey is given, formulæ used are derived, and their method of application explained.

LIST OF SYMBOLS USED

A	Cross-sectional areas of a tank (sq. ft.)
a, a_1, a_2	Numerical constants
b, b_1, b_2	Numerical constants
C	A tank capacity (ft)
D	The density of petrol evaporate (lb/I.G.)
Do	A tank diameter (ft)
E	% change in end sample determined by Chenicek–Whitman apparatus after correction for transfer of petrol to vapour space
e	Thermal breathing loss expressed as percentage loss of tank capacity
f	A saturation factor (100 per cent saturation at bulk liquid temperature = 1)
G	A pumping down loss (ft of petrol vapour at 760 mm Hg and temperature T)
H	Height of tank to eaves (ft)
h	Depth of petrol (not including water bottom) in tank (ft)
I	Innage factor ($I = 1$ when innage is $(H - 1)$ ft)
k	Ratio of shell area of tank (roof included and tank bottom excluded), to vapour space volume at the given innage (ft^{-1})
L	An annual loss factor
M	Molecular weight of petrol evaporate
N	Duration of test in days
n	Number of days at which tank stands at a given innage
P	Absolute pressure in tank (units either mm Hg or inches w.g. as stated)
p	Absolute vapour pressure of petrol at bulk liquid storage temperature (mm Hg)
p_i	Initial mean vapour pressure immediately after a pumping down (mm Hg)
p_f	Final mean vapour pressure after standing for n days (mm Hg)
Q	Evaporation loss expressed in percentage of tank capacity
R	A temperature range (° F)
Ri	Mean daily effective internal temperature range (° F)
Re	Mean daily external temperature range (° F)
Ra	Annual mean daily external temperature range (° F)
S	Mean percentage saturation of vapour space, referred to mean bulk liquid storage temperature
T	Bulk liquid storage temperature (° F, absolute)
T_1, T_2, etc.	Other absolute Fahrenheit temperatures as specified
U	Percentage evaporated from a sample in the Chenicek–Whitman apparatus
V	Vapour space volume (ft)
v_1, v_2, etc.	Volumes of petrol vapour under conditions specified (ft)
Y	A breathing loss term
y	Ratio of the mean internal effective temperature range to the mean external temperature range
Z	An evaporation loss term
θ	Total breather valve range (inches w.g.)

INTRODUCTION

Evaporation Loss—General Considerations

THE problem of evaporation loss from storage tanks containing volatile liquids is by no means new or unfamiliar in the petroleum industry. Since the early 1920s various aspects of this subject have been examined, particularly with respect to its physical causes and mechanism. For this reason only a brief outline is given here.

Evaporation loss from fixed-roof storage tanks can be considered under the following headings:

(*a*) Thermal breathing loss.
(*b*) Pumping-down loss.
(*c*) Filling loss.
(*d*) Windage loss.

Thermal breathing loss is caused by the repetitive daily heating and nightly cooling of the tank shell leading directly to:

(i) temperature rise and fall in the tank vapour space;

(ii) temperature rise and fall of the liquid petrol surface, which in turn leads to a rise during the

* MS received 14 January 1955.

† Wheatsoe Ltd.

day of the vapour pressure of petrol in the vapour space;

(iii) occasional condensation on and re-evaporation from the exposed inside surface of the tank shell.

These three effects together result in a daily pressure variation in the vapour space, and if this exceeds the range of setting of the pressure and vacuum relief valves, air–petrol vapour mixture will be expelled during the day and replaced by an in-breathe of air at night. The lost vapour will subsequently be replaced by evaporation from the liquid which is continuously attempting to produce a state of saturation relative to its surface temperature in the air–petrol vapour mixture with which it is in contact. Contact between liquid and unsaturated air–petrol vapour mixture is maintained largely by convection eddy currents which develop in the vapour space, particularly during the night when the tank roof temperature can fall below the liquid surface temperature, thus tending to reverse the normal daytime temperature gradient.

It might be thought that change in barometric pressure could also be responsible for some breathing loss, for if the tank vapour space pressure is just equal to the breather valve pressure setting when a fall in barometric pressure occurs, then a breathe of air–petrol vapour mixture will take place. However, the exact converse of this situation can occur, *i.e.* a rise in barometric pressure can prevent a breathe which would otherwise occur if the barometric pressure remained constant. As both these events are equally likely, no additional loss would be expected over reasonable periods of time. Under the test conditions described in this paper this effect would be inappreciable, and is not considered further.

Pumping-down loss is due to the indrawing of air into the tank during a pumping-down operation. During the time in which the tank contents remain stationary, *i.e.* until the next pumping-down operation takes place, the indrawn air mixes with the air–petrol vapour mixture initially present in the tank, and as the mixing process is accompanied by evaporation from the liquid, a rise in pressure takes place in the vapour space. Thus, partially saturated air–petrol vapour mixture of gradually increasing petrol content is expelled from the tank. It is emphasized that this loss has no connexion with thermal breathing loss.

Filling loss. As a result of air indrawing and evaporation of liquid into the vapour space of the tank during the pumping down and subsequent standing periods, the tank is normally left full of air nearly saturated with petrol vapour. When petrol is pumped into the tank an equivalent volume of this air–petrol vapour mixture is displaced from the tank, and a filling loss occurs. This displacement loss is increased somewhat by further evaporation during the pumping-in operation, if the vapour pressure of the added spirit is higher than that already existing in the vapour space.

Windage Loss. Open vents result in greatly increased losses from tanks storing volatile liquids. Gusty or turbulent winds blowing across an open vent cause rapid pressure variations at the vent, resulting in additional breathing in the form of rapid, short puffs. Any leak in a tank roof or accessory must be to some extent equivalent to an open vent. Where more than one leak or opening is present the loss is likely to be still further increased, as air pressure differences across the tank roof can cause inflow of air through one opening and an outflow of air–petrol vapour mixture through another.

Brief Review of Published Information

A full description of the mechanism of evaporation losses is given in an API Symposium on Evaporation Loss.[1] This publication also shows a comparison of the results of several company methods of estimating breathing losses from cone roof tanks, these companies having developed their own methods for estimating evaporation losses by piecing together all available data into workable formulæ, charts, and tables. The spread of the figures is considerable. Commenting generally on the practical problem of estimating evaporation losses, the Symposium states that, "It seems as though in evaporation-loss work there is a wider abundance of opinions, in contrast to a marked scarcity of facts, than is the case in most studies having a technical background."

In 1938 Ashley [2] attempted to correlate all the data on evaporation loss available at that time. In his conclusions he states that "a detailed review of a large amount of data on evaporation losses indicates that much of the information that has been published as comparable is not comparable, because there has been no common basis for comparison." The few figures given for full fixed-roof tanks show a considerable spread.

Sarjeant's paper [3] indicates simple calculations by which the main order of thermal breathing loss to be anticipated from normally operated storage tanks can be obtained.

A technical publication of the Chicago Bridge and Iron Company [4] gives a nomogram showing the thermal breathing loss as a function of vapour pressure at storage temperature, tank size, and innage; the diagram is based on a large number of Chenicek-Whitman determinations.

Happel and Heath [5] give data on the rate of change of vapour pressure in a small tank following a pumping-down operation, and give a simple method of calculating the combined pumping-down and filling loss from a tank.

Many other publications are concerned with methods of calculating losses in given circumstances, methods of preventing or limiting losses, the effects of isolated factors such as paintwork, roof-lagging, water sprays, methods of measuring losses, etc.

All this information, valuable as it undoubtedly is as a guide to further study and experimentation, does not give the particular information required, *i.e.* there is no correlation of practically determined losses with the various main factors governing losses in the U.K.

The information on losses in the U.S.A. is for

climatic conditions and breather valve loadings different from those in the U.K., and although the U.S. results could be modified by calculation, provided that suitable assumptions were made, it is felt that without the backing of practically determined losses in the U.K. the results would be of doubtful value.

The above considerations formed the general background to the decision to carry out an evaporation loss survey, the main object of the work being to obtain a survey of thermal breathing losses only, and if possible to derive a correlation between thermal breathing losses and prevailing conditions so that from a knowledge of these conditions thermal breathing losses could be predicted.

As will be seen later, owing to the fact that many of the tanks under investigation were working tanks, a method had to be developed for the calculation of pumping-down losses.

Preliminary Work on an Experimental Tank

Before work on the survey could be commenced, one of the first matters requiring a decision was the method to be used for measuring evaporation loss.

In obtaining the U.S. results the Chenicek–Whitman method was used extensively. In principle, this method involves taking an initial sample of petrol from a tank at the beginning of the test period, and determining its vapour pressure. At the end of the test period, during which time evaporation losses have occurred, a second sample is taken, and its vapour pressure determined. This vapour pressure will be lower than that of the initial sample, since, when evaporation occurs, the more volatile constituents of the petrol are lost to a greater extent than the less volatile. From the difference in vapour pressure between the two samples and from the experimental method of determining these vapour pressures, it is possible to arrive at the evaporation loss which has occurred (see p. 317).

As an alternative to the Chenicek–Whitman method, it was considered that a more direct method involving measurement of the actual air–petrol vapour mixture escaping from the tank might be preferable. After preliminary laboratory work it was concluded that this method was sufficiently promising to justify a trial. An experimental tank was installed at Darlington so that the method could be tried out before proceeding to large-scale tests on tank sites.

As a basic check, it was arranged that the evaporation loss could be determined by direct dip measurement, *i.e.* the depth of petrol in the tank could be measured accurately at the beginning and end of the test, and from these measurements, coupled with initial and final bulk temperature and density measurements, the loss could be determined.

For comparison purposes, simultaneous measurement of the loss, using the Chenicek–Whitman method, was carried out. Thus the loss was measured by three separate methods :

(i) Volume measurement of air–petrol vapour mixture leaving the tank.

(ii) Chenicek–Whitman method.

(iii) Direct-dip method, as a basic check for (i) and (ii) above.

An exhaustive survey of factors affecting the accuracy of the basic " dip " method was undertaken in order to determine the nature and accuracy of the measurements required, *e.g.* experiments were carried out to check the reproducibility of density determinations, micrometer dip readings, and thermo-couple readings, and to assess the effect of shell expansion.

The size of the experimental tank (9 ft dia × 10 ft high) and the depth of petrol (3 ft approx) were chosen with a view to obtaining an accurately measurable loss in a period of two or three months. To avoid error in the direct dip measurement as a result of warping, the tank bottom was made of 1 inch M.S. plates and the bottom course of ½ inch M.S. plate. The tank was carefully set on a heavy, weathered, concrete foundation. Two micrometers were provided, diametrically opposite each other on the tank side, for the dip measurements. The bulk temperature measurements were obtained from thirty-two thermo-couples suitably spaced in the 3 ft of liquid petrol.

Two tests were carried out, (*a*) from towards the end of July to the end of August 1951, and (*b*) from mid-September 1951 to mid-May 1952. The results were as follows :

	Per cent
(*a*) Loss by Chenicek–Whitman method . .	0·54
Loss by breathe measurement method .	0·49
Loss by direct dip method . . .	0·52
(*b*) Loss by Chenicek–Whitman method . .	1·45
Loss by breathe measurement method .	1·66
Loss by direct dip method . . .	1·46

In view of these results and also because experience showed the breathe measurement method to be somewhat cumbersome and probably difficult to apply to large-scale site work, the Chenicek–Whitman method was adopted for the evaporation loss survey.

Choice of Tanks for the Survey

For a comprehensive survey, the tanks chosen for investigation should be spread as widely as possible over the country in order to take into account different climatic conditions. Ideally, these tanks should be standing tanks, *i.e.* no petrol pumped in or out over a period of two to four months, covering a wide range of sizes, several tanks in each size standing at different innages from empty to full. As might be expected, owing to practical operational requirements at tank sites, this ideal could not be attained, but with the full co-operation of the oil companies concerned, it was found possible to allocate sufficient tanks to enable a worth-while survey to be carried out. These tanks included a substantial proportion of working tanks, *i.e.* those from which petrol was removed from time to time during the test, and the Chenicek–Whitman results for the latter had to be corrected for the various effects associated with these pumping-down operations. The Chenicek–Whitman method

cannot be applied if petrol is pumped into the tank during the test period.

The oil companies co-operating in this work were Esso Petroleum Co. Ltd., Regent Oil Co. Ltd., and Shell-Mex and B.P. Ltd., and these companies made tankage available for test purposes on the Clyde, Forth, Tweed, Humber, Thames, Severn, and Mersey.

Thirty-six tanks were investigated, their sizes ranging from 20 ft dia × 20 ft up to 105 ft dia × 24·5 ft, and including three 9 ft dia × 30 ft horizontals. These tanks were aluminium painted, with the exception of one group of five tanks painted green, and one tank painted black with a surrounding brick wall. The aluminium painted tanks were all in "normal" condition, *i.e.* neither newly painted nor in need of immediate repainting. From these thirty-six tanks, 127 complete evaporation loss measurements were made.

The breather valve settings for the different tanks covered the range of values:

+3 inch and −1 inch w.g.
+4 inch and −1 inch w.g.
+7 inch and −2·75 inches w.g.
+8 inch and −2·5 inches w.g.
+20 inch and −2·5 inches w.g.

In addition, four tanks had valves of negligible loading and five tanks, including the 9 ft × 30 ft tanks, were freely vented.

With one exception, none of the tanks under test had special gauging equipment, so that the losses measured included normal gauging losses.

The degree of tightness of the tanks varied greatly. This was considered to be an advantage as far as obtaining a survey of typical thermal breathing losses, representative of present storage practice, is concerned. For obtaining a correlation between thermal breathing losses and operating conditions, however, attention had to be confined to "tight" tanks, as it is obvious that losses from leaks are of such a haphazard nature that any attempt to introduce them into a correlation is out of the question. Tanks classified as "tight" were those with no known sources of leakage or those where the leak was assessed as being unimportant. The methods adopted to distinguish between "tight" tanks and leaking tanks are described in a later section.

While the correlation curve obtained can be used only to predict losses from "tight" tanks, it is suggested that the results obtained from leaking tanks, considered in relation to the correlation curve, provide some indication of the order of maximum losses to be expected. This point is discussed in more detail later.

APPLICATION OF THE CHENICEK–WHITMAN RESULTS

Standing Tanks

When storage tanks are standing, evaporation loss occurs only by thermal breathing. The Chenicek–Whitman results can therefore be applied directly. No estimated corrections are required for losses from other causes, and the results give a direct measurement of thermal breathing loss.

The Chenicek–Whitman result is obtained in the form "percentage volume loss from the final sample." To express this loss in terms of percentage of tank capacity, the Chenicek–Whitman result is simply multiplied by the volume of liquid petrol, expressed as a fraction of tank capacity, present during the test period.

Working Tanks

Vapour space loss and pumping-down loss. The pumping down of a tank normally occurs in stages. Following the removal of any substantial amount of petrol and during the time in which the contents remain stationary, *i.e.* until the next pumping-down operation takes place, the indrawn air mixes with the air–petrol vapour mixture initially present in the tank, and this mixing process is accompanied by evaporation from the liquid and an increase of pressure in the tank vapour space.

A part of the petrol lost from the liquid by evaporation stays in the increased vapour space, while a part is lost from the tank as a result of the pressure rise. As neither loss is in any way connected with thermal breathing, a correction has to be applied to the Chenicek–Whitman result to take care of these effects.

The percentage loss from the final sample caused at each stage by transfer of petrol from liquid to the vapour space, and remaining in the vapour space, is termed throughout the present paper as "vapour space loss."

The percentage loss from the final sample caused at each stage by loss of vapour from the tank due to the pressure rise in the vapour space, as described above, is termed "pumping-down loss."

The effect of varying innage. Thermal breathing losses and the vapour space and pumping-down losses mentioned above occur in a number of stages at a corresponding number of innages, whereas the final Chenicek–Whitman sample is taken from the smallest innage. In order to interpret the Chenicek–Whitman result, these varying conditions must be taken into account by determining what may be termed the "effective average volume" of liquid petrol in the tank during the test period.

The methods used to assess quantitatively the effects under Working Tanks above are discussed in detail in the Appendix.

SITE WORK

Sampling

Evaporation loss measurement by the Chenicek–Whitman method results from vapour pressure measurements on an initial petrol sample taken at the beginning of the test and on a final sample taken at the end of the test. These samples must obviously be representative of the bulk of the liquid petrol in the tank, and precautions must be taken to ensure that

none of the lighter fractions is lost from the sample, either during sampling or subsequent operations.

Chenicek and Whitman [6] carried out tests on a storage tank to establish a suitable sampling procedure. Samples were taken from near the surface of the petrol in the tank and also at intervals throughout the depth of the petrol. Only the sample from near the surface showed any appreciable difference from the remainder, and the results of this work established that a sample from the midpoint of the depth would be adequately representative of the petrol in the tank.

This conclusion was confirmed by the authors' results, shown in Table I, obtained on a 118-ft dia tank containing approx 28 ft of petrol.

TABLE I

Depth of sample below surface, ft	Vapour pressure at 75° F, mm Hg	Vapour pressure at 75° F after 1% evaporation, mm Hg
0	350·0	329·0
1	352·0	331·0
2	353·0	332·0
3	353·5	333·0
4	354·0	333·0
14	354·0	333·0
24	354·0	333·0
25	354·0	333·0
26	353·0	332·0
27	352·0	331·0
28	350·5	330·0

At the start of this work samples were taken in a conventional copper sampling can. The stoppered can was lowered to the required depth and the stopper removed by jerking its string attachment, thus allowing the can to fill with petrol. It was then withdrawn from the tank, emptied a portion at a time, the can being well shaken between the removal of successive portions, so that finally the can was left full of saturated air–petrol vapour mixture. The can was then re-stoppered. The process of filling the can at the required depth was then repeated, the can being stoppered immediately on withdrawal from the tank. The sample was then transferred by water displacement to another container for transport and storage.

The above method was satisfactory, but was soon superseded by a quicker and more convenient one. In this method a brass cage of suitable size to hold a 500-cc bottle is attached to the end of a Bowden cable, made from a steel cable threaded through a length of polyvinyl chloride tubing (Fig 1). The latter is attached to the top of the cage side by means of a brass rod, the attachment allowing the cage to pivot about the end of the brass rod. The steel cable is attached to the bottom of the cage.

The procedure for taking a sample is as follows :

A 500-cc bottle, which is now both the sampling and storage bottle, is completely filled with water and placed in the cage, which is lowered to the mid-depth of the petrol by means of the P.V.C. tubing. On pulling the steel cable from above, through the P.V.C. tubing, the cage and bottle are inverted, thus allowing water to flow out and to be replaced by petrol. After allowing sufficient time for the water to be completely displaced, the cable is released from above, allowing the cage and bottle to return to their original upright position. The cage and bottle are then withdrawn from the tank. The bottle is stoppered

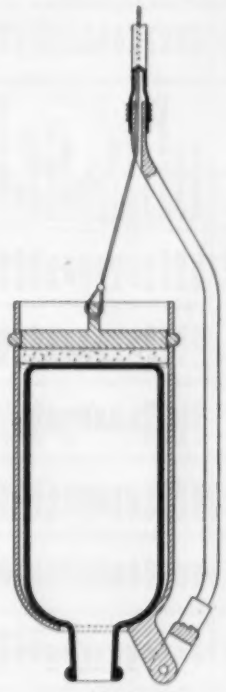

FIG 1
PETROL SAMPLING DEVICE

immediately, sealed by means of a "Viscap," transported to the laboratory in a rubber lined box, and stored in a cold-water jacketed container.

As importance was attached to correct sampling, throughout the work initial and final samples were taken in duplicate by one of the authors. In every case both samples were tested.

Tank Records

After taking samples from a working tank, the details of the tank working were obtained from site record sheets. These details comprised the dip readings giving innages (including water bottom) before and after each movement of petrol from the tank, and the bulk liquid temperatures, which were generally taken at approximately weekly intervals.

RESULTS

All the results obtained, together with tank details, external temperature conditions, etc., are given in Table II.

TABLE II

	Initial sample date	Final sample date	Time under test, days	Tank size dia × ht, ft	Nominal valve settings, inches w.g.	State of tank	Mean % innage during test	Mean saturation vapour pressure, mm Hg	Loss in % of tank capacity				Location	External temperature conditions during test		k	y
									Total measured loss	Pumping-down loss	Thermal breathing loss	Thermal breathing loss/day × 100		Mean temperature range, °F	Mean temperature, °F		
1	22. 9.52	29.10.52	37	46 × 35·25	+8 −2·5	"Tight"	87	133	0·041	0·009	0·032	0·087	Merseyside	7·2	47·8	0·59	6·2
2	22. 9.52	29.10.52	37	52 × 35	+20 −2·5	"Tight"	77	116	0·024	0·011	0·013	0·035	Merseyside	7·2	47·8	—	—
3	14.10.52	27.11.52	43	30 × 30	+6 −2·5	"Tight"	58	166	0·092	0·017	0·075	0·174	Thames Estuary	9·7	45·3	0·35	3·4
4	29. 9.52	4.11.52	35	39 × 24	+8 −2	"Tight"	63	185	0·077	0·022	0·055	0·16	Severn	10·4	50·2	0·32	3·0
5	23. 9.52	17.12.52	85	92 × 33·75	+8 −2·5	"Tight"	100	205	Nil	Nil	Nil	Nil	Merseyside	6·9	44·7	—	—
6	23. 9.52	17.12.52	85	92 × 33·75	+8 −2·5	Leaking	100	203	0·04	Nil	0·04	0·05	Merseyside	6·9	44·7	—	—
7	3.10.52	13.12.52	71	35 × 25	+8 −2	"Tight"	100	170	Nil	Nil	Nil	Nil	Forth	8·1	41·9	—	—
8	28.10.52	12.12.52	45	105 × 24·3	+4 −1	"Tight"	100	218	Nil	Nil	Nil	Nil	Clyde	9·7	39·5	—	—
9	6.11.52	16.12.52	40	80 × 30	+4 −2	"Tight"	69	268	Nil	0·02	Nil	Nil	Merseyside	6·3	40·4	—	—
10	6.10.52	18.12.52	73	9 × 30 *	Free vent	—	100	182	0·35	Nil	0·35	0·48	Nottingham	10·5	42·3	—	—
11	17.12.52	13. 1.53	27	80 × 30	+4 −2	"Tight"	26	260	0·039	0·025	0·014	0·052	Merseyside	7·2	38·0	0·10	1·4
12	23.10.52	5. 1.53	74	30 × 30	+3 −1	"Tight"	87	114	0·118	0·003	0·115	0·154	Kent	11·3	39·4	0·87	6·5
13	15.10.52	2. 1.53	79	60 × 30	+3 −1	"Tight"	92·5	91	0·082	0·002	0·080	0·101	Thames Estuary	9·2	42·4	0·79	7·4
14	18.12.52	19. 3.53	91	92 × 33·75	+8 −2·5	"Tight"	100	186	0·06	Nil	0·06	0·066	Merseyside	8·0	40·0	0·63	5·1
15	16. 1.53	9. 4.53	83	105 × 24·3	+4 −1	"Tight"	100	253	0·10	Nil	0·10	0·12	Clyde	12·2	41·8	0·41	3·9
16	21. 1.53	19. 3.53	57	80 × 30	+4 −2	"Tight"	90	290	0·124	0·045	0·079	0·139	Merseyside	8·3	41·1	0·53	4·4
17	19.12.52	18. 2.53	61	80 × 30	+4 −1	"Tight"	53	255	0·121	0·035	0·086	0·141	Humber	8·0	40·0	0·16	2·1
18	7.11.52	16.12.52	39	46 × 35·25	+8 −2·5	"Tight"	100	168	Nil	Nil	Nil	Nil	Merseyside	6·7	38·9	—	—
19	7. 1.53	10. 6.53	154	60 × 30	+3 −1	"Tight"	102	120	0·18	Nil	0·18	0·12	Thames Estuary	12·7	47·8	1·25	10·2
20	25. 3.53	29. 4.53	35	80 × 30	+4 −2	"Tight"	52	305	0·248	0·034	0·214	0·61	Merseyside	11·6	45·2	0·16	3·9
21	12. 3.53	14. 5.53	63	50 × 40	Atmospheric †	Leaking	97	234	0·10	Nil	0·10	0·16	Humber	14·7	46·1	1·08	4·8
22	24. 3.53	14. 5.53	51	82·5 × 40	Atmospheric †	Leaking	100	242	0·09	Nil	0·09	0·18	Humber	13·9	46·6	0·78	5·7
23	27. 3.53	15. 5.53	49	20 × 20	+8 −2	"Tight"	45	210	0·339	0·023	0·316	0·645	Humber	13·9	46·6	0·42	4·5
24	17. 4.53	28. 5.53	41	35 × 25	+8 −2	"Tight"	78	246	0·155	Nil	0·155	0·378	Forth	12·6	48·6	0·53	5·1
25	15. 4.53	10. 6.53	56	92 × 33·75	+7 −2·75	Leaking	99	285	0·30	Nil	0·30	0·53	Severn	15·7	53·0	0·56	9·0
26	15. 4.53	10. 6.53	56	92 × 33·75	+7 −2·75	Leaking	95	285	0·28	Nil	0·28	0·50	Severn	15·7	53·0	0·43	6·5
27	15. 4.53	10. 6.53	56	92 × 33·75	+7 −2·75	Leaking	93	320	0·21	Nil	0·21	0·37	Severn	15·7	53·0	0·39	3·8
28	15. 4.53	10. 6.53	56	92 × 33·75	+7 −2·75	Leaking	95	275	0·17	Nil	0·17	0·30	Severn	15·7	53·0	0·43	4·1
29	15. 4.53	10. 6.53	56	92 × 33·75	+7 −2·75	Leaking	87	275	0·20	Nil	0·20	0·36	Severn	15·7	53·0	0·31	3·2
30	6. 5.53	18. 6.53	43	80 × 30	+4 −2	"Tight"	60	350	0·255	0·112	0·143	0·33	Merseyside	10·9	54·6	0·19	2·7
31	30. 4.53	29. 5.53	29	46 × 35·25	+8 −2·5	"Tight"	8	230	0·115	Nil	0·115	0·40	Merseyside	12·4	53·7	0·12	2·6
32	19. 3.53	18. 6.53	91	92 × 33·75	+8 −2·5	"Tight"	100	230	0·11	Nil	0·11	0·12	Merseyside	11·5	49·8	0·63	4·8
33	19. 3.53	18. 6.53	91	92 × 33·75	+8 −2·5	Leaking	100	238	0·18	Nil	0·18	0·20	Merseyside	11·5	49·8	0·63	5·7
34	19. 3.53	18. 6.53	91	92 × 33·75	+8 −2·5	Leaking	100	220	0·14	Nil	0·14	0·15	Merseyside	11·5	49·8	0·63	4·8
35	19. 3.53	18. 6.53	91	92 × 33·75	+8 −2·5	Leaking	100	215	0·18	Nil	0·18	0·20	Merseyside	11·5	49·8	0·63	6·3
36	7. 4.53	26. 6.53	80	9 × 30 *	Free vent	—	100	255	0·58	Nil	0·58	0·73	Humber	9·8	48·7	—	—
37	7. 4.53	26. 6.53	80	9 × 30 *	Free vent	—	50	244	1·13	Nil	1·13	1·41	Humber	9·8	48·7	—	—
38	31. 3.53	23. 6.53	84	92 × 33·75	+8 −2·5	Leaking	96	220	0·39	Nil	0·39	0·46	Severn	14·9	52·7	0·45	8·7
39	31. 3.53	23. 6.53	84	92 × 33·75	+8 −2·5	Leaking	94	228	0·32	Nil	0·32	0·38	Severn	14·9	52·7	0·41	6·1
40	31. 3.53	23. 6.53	84	92 × 33·75	+8 −2·5	Leaking	94	230	0·25	Nil	0·25	0·30	Severn	14·9	52·7	0·41	4·7
41	31. 3.53	23. 6.53	84	92 × 33·75	+8 −2·5	Leaking	96	230	0·23	Nil	0·23	0·27	Severn	14·9	52·7	0·45	4·9
42	31. 3.53	23. 6.53	84	92 × 33·75	+8 −2·5	Leaking	95·5	225	0·38	Nil	0·38	0·45	Severn	14·9	52·7	0·44	7·9
43	14. 5.53	3. 7.53	50	70 × 35	Atmospheric †	Leaking	99	290	0·25	Nil	0·25	0·50	Humber	13·9	58·0	0·81	12·3
44	14. 5.53	3. 7.53	50	60 × 28·5	Atmospheric †	Leaking	98	344	0·26	Nil	0·26	0·52	Humber	13·9	58·0	0·81	9·1
45	19. 6.53	28. 7.53	39	80 × 30	+4 −2	"Tight"	69·5	385	0·224	0·104	0·120	0·308	Merseyside	11·5	60·5	0·24	2·8
46	8. 6.53	16. 7.53	38	52 × 35	+20 −2·5	"Tight"	53	257	0·09	0·03	0·06	0·16	Merseyside	11·0	59·3	—	—
47	26. 6.53	14. 8.53	49	20 × 20	+8 −2	"Tight"	98·5	283	0·28	Nil	0·28	0·57	Humber	15·6	62·0	2·58	13·7
48	26. 6.53	14. 8.53	49	9 × 30 *	Free vent	—	50	296	0·67	Nil	0·67	1·37	Humber	15·6	62·0	—	—
49	26. 6.53	14. 8.53	49	9 × 30 *	Free vent	—	100	322	0·49	Nil	0·49	1·00	Humber	15·6	62·0	—	—
50	7. 7.53	3. 9.53	58	105 × 24·3	+4 −1	"Tight"	97·4	388	0·11	Nil	0·11	0·19	Clyde	13·9	64·4	0·33	3·2
51	28. 5.53	3. 9.53	98	35 × 25	+8 −2	"Tight"	76·0	254	0·37	Nil	0·37	0·38	Forth	12·0	56·9	0·50	5·1
52	30. 7.53	9. 9.53	41	80 × 30	+4 −2	"Tight"	61	350	0·288	0·085	0·203	0·495	Merseyside	10·5	60·2	0·15	3·9
53	10. 6.53	8. 9.53	90	92 × 33·75	+7 −2·75	Leaking	99	290	0·53	Nil	0·53	0·59	Severn	13·9	61·2	0·56	11·3
54	10. 6.53	8. 9.53	90	92 × 33·75	+7 −2·75	Leaking	95	296	0·43	Nil	0·43	0·48	Severn	13·9	61·2	0·43	6·9
55	10. 6.53	8. 9.53	90	92 × 33·75	+7 −2·75	Leaking	93	335	0·31	Nil	0·31	0·34	Severn	13·9	61·2	0·39	3·9
56	10. 6.53	8. 9.53	90	92 × 33·75	+7 −2·75	Leaking	95	287	0·41	Nil	0·41	0·46	Severn	13·9	61·2	0·43	6·7
57	10. 6.53	8. 9.53	90	92 × 33·75	+7 −2·75	Leaking	87	287	0·36	Nil	0·36	0·40	Severn	13·9	61·2	0·31	3·9
58	18. 6.53	17. 9.53	91	92 × 33·75	+8 −2·5	"Tight"	100	280	0·19	Nil	0·19	0·21	Merseyside	10·5	60·0	0·63	7·1

59	18. 6.53	17. 9.53	91	92 × 33·75	+8	−2·5	Leaking	100	259	0·21	Nil	0·21	0·23	Merseyside	10·5	60·0	0·63	7·0
60	18. 6.53	17. 9.53	91	92 × 33·75	+8	−2·5	Leaking	100	271	0·17	Nil	0·17	0·19	Merseyside	10·5	60·0	0·63	5·3
61	18. 6.53	17. 9.53	91	92 × 33·75	+8	−2·5	Leaking	100	283	0·29	Nil	0·29	0·32	Merseyside	10·5	60·0	0·63	8·8
62	10. 6.53	15. 9.53	97	60 × 30	+3	−1	"Tight"	70	120	0·170	0·006	0·164	0·169	Thames Estuary	15·8	63·1	0·29	2·8
63	23. 6.53	23. 9.53	92	92 × 33·75	+8	−2·5	Leaking	96	263	0·33	Nil	0·33	0·36	Severn	13·6	62·0	0·45	6·3
64	23. 6.53	23. 9.53	92	92 × 33·75	+8	−2·5	Leaking	94	273	0·42	Nil	0·42	0·46	Severn	13·6	62·0	0·41	6·9
65	23. 6.53	23. 9.53	92	92 × 33·75	+8	−2·5	Leaking	94	278	0·29	Nil	0·29	0·32	Severn	13·6	62·0	0·41	4·7
66	23. 6.53	23. 9.53	92	92 × 33·75	+8	−2·5	Leaking	96	276	0·22	Nil	0·22	0·24	Severn	13·6	62·0	0·45	4·0
67	23. 6.53	23. 9.53	92	92 × 33·75	+8	−2·5	Leaking	95·5	271	0·24	Nil	0·24	0·26	Severn	13·6	62·0	0·44	4·3
68	28. 8.53	30.10.53	63	9 × 30	Free vent		—	100	314	0·23	Nil	0·23	0·38	Humber	15·8	55·5	—	—
69	28. 8.53	30.10.53	63	9 × 30 *	Free vent		—	50	303	0·47	Nil	0·47	0·75	Humber	15·8	55·5	—	—
70	9.10.53	6.11.53	28	80 × 30	+4	−1	"Tight"	39	335	0·21	0·07	0·14	0·50	Humber	12·7	46·2	0·13	2·3
71	3. 9.53	24.11.53	82	105 × 24·3	+4	−1	"Tight"	36	250	0·15	0·05	0·10	0·12	Clyde	10·5	51·2	0·06	1·3
72	30.10.53	27.11.53	28	9 × 30 *	Free vent		—	100	265	0·10	Nil	0·10	0·36	Humber	8·9	46·8	—	—
73	30.10.53	27.11.53	28	9 × 30 *	Free vent		—	50	252	0·15	Nil	0·15	0·54	Humber	8·9	46·8	—	—
74	12.10.53	3.12.53	52	30 × 30	Free vent		—	65	206	0·35	0·02	0·33	0·63	Tweed	8·6	46·9	0·42	8·9
75	24.11.53	14. 1.54	51	105 × 24·3	+4	−1	"Tight"	9·6	191	0·058	Nil	0·058	0·114	Clyde	8·0	43·0	0·05	1·6
76	7.12.53	13. 1.54	37	80 × 30	+4	−1	"Tight"	82	300	0·12	0·03	0·09	0·19	Humber	7·4	41·6	0·36	5·4
77	22.10.53	14. 1.54	84	60 × 30	+3	−1	"Tight"	81	203	0·19	0·03	0·16	0·19	Thames	8·8	42·0	0·35	4·3
78	25.11.53	18.12.53	23	80 × 30	+4	−2	"Tight"	83	314	0·02	0·02	Nil	Nil	Merseyside	6·3	43·7	—	—
79	11.12.53	20. 2.54	71	30 × 30	Free vent		—	50·2	175	0·45	0·01	0·44	0·62	Tweed	7·9	38·1	0·31	7·9
80	11.12.53	20. 2.54	71	30 × 30	Free vent		—	57·8	223	0·75	0·04	0·71	1·00	Tweed	7·9	38·1	0·35	11·5
81	12.11.53	19. 2.54	99	20 × 20	+8	−2	"Tight"	100	179	0·12	Nil	0·12	0·12	Humber	7·3	40·0	2·94	12·1
82	8. 9.53	3. 3.54	176	92 × 33·75	+7	−2·75	"Tight"	97·5	240	0·32	Nil	0·32	0·18	Severn	10·6	51·2	0·50	5·7
83	8. 9.53	3. 3.54	176	92 × 33·75	+7	−2·75	"Tight"	94·0	245	0·26	Nil	0·26	0·15	Severn	10·6	51·2	0·41	4·4
84	8. 9.53	3. 3.54	176	92 × 33·75	+7	−2·75	"Tight"	92·8	278	0·26	Nil	0·26	0·15	Severn	10·6	51·2	0·39	3·7
85	8. 9.53	3. 3.54	176	92 × 33·75	+7	−2·75	"Tight"	96·2	239	0·11	Nil	0·11	0·06	Severn	10·6	51·2	0·46	2·7
86	8. 9.53	3. 3.54	176	92 × 33·75	+7	−2·75	"Tight"	86·4	237	0·23	Nil	0·23	0·13	Severn	10·6	51·2	0·31	3·1
87	2.12.53	1. 3.54	89	9 × 30 *	Free vent		—	100	193	0·18	Nil	0·18	0·20	Humber	7·6	39·8	—	—
88	2.12.53	1. 3.54	89	9 × 30 *	Free vent		—	50	192	0·33	Nil	0·33	0·37	Humber	7·6	39·8	—	—
89	12. 2.54	22. 3.54	38	32 × 35	+20	−2·5	"Tight"	7·4	150	0·027	0·002	0·025	0·066	Merseyside	8·9	40·4	—	—
90	5. 1.54	4. 3.54	58	80 × 30	+4	−2	"Tight"	96·7	303	0·07	Nil	0·07	0·12	Merseyside	7·4	37·7	0·88	6·4
91	25. 1.54	8. 3.54	42	80 × 30	+4	−1	"Tight"	61·6	275	0·17	0·06	0·11	0·26	Humber	9·0	35·6	0·20	3·0
92	17. 9.53	23. 3.54	187	92 × 33·75	+8	−2·5	Leaking	100	192	0·17	Nil	0·17	0·09	Merseyside	8·0	44·0	0·63	4·6
93	17. 9.53	23. 3.54	187	92 × 33·75	+8	−2·5	Leaking	100	199	0·30	Nil	0·30	0·16	Merseyside	8·0	44·0	0·63	7·8
94	17. 9.53	23. 3.54	187	92 × 33·75	+8	−2·5	"Tight"	100	208	0·13	Nil	0·13	0·07	Merseyside	8·0	44·0	0·63	3·3
95	17. 9.53	23. 3.54	187	92 × 33·75	+8	−2·5	Leaking	100	208	0·25	Nil	0·25	0·13	Merseyside	8·0	44·0	0·63	6·2
96	23. 9.53	30. 3.54	188	92 × 33·75	+8	−2·5	Leaking	94·6	192	0·25	Nil	0·25	0·13	Severn	10·5	45·3	0·42	3·6
97	23. 9.53	30. 3.54	188	92 × 33·75	+8	−2·5	Leaking	91·5	198	0·27	Nil	0·27	0·14	Severn	10·5	45·3	0·36	3·2
98	23. 9.53	30. 3.54	188	92 × 33·75	+8	−2·5	Leaking	92·2	201	0·39	Nil	0·39	0·21	Severn	10·5	45·3	0·37	4·7
99	23. 9.53	30. 3.54	188	92 × 33·75	+8	−2·5	Leaking	94·6	203	0·49	Nil	0·49	0·26	Severn	10·5	45·3	0·42	6·6
100	23. 9.53	30. 3.54	188	92 × 33·75	+8	−2·5	Leaking	93·8	198	0·09	Nil	0·09	0·05	Severn	10·5	45·3	0·41	1·0
101	4. 3.54	1. 4.54	28	80 × 30	+4	−2	"Tight"	90·7	328	0·15	0·07	0·08	0·29	Merseyside	9·5	44·2	0·55	6·7
102	26. 2.54	9. 4.54	42	105 × 24·3	+4	−1	"Tight"	100·8	305	0·06	Nil	0·06	0·14	Clyde	11·3	42·0	0·44	4·4
103	1. 3.54	26. 4.54	56	20 × 20	+8	−2	"Tight"	96·8	244	0·21	Nil	0·21	0·38	Humber	12·2	43·8	2·17	11·7
104	15. 3.54	23. 4.54	39	30 × 30	Free vent		—	58·0	230	0·56	0·02	0·54	1·38	Tweed	11·6	43·6	0·35	10·9
105	15. 3.54	23. 4.54	39	30 × 30	Free vent		—	49·0	275	0·96	0·02	0·94	2·41	Tweed	11·6	43·6	0·30	13·4
106	7. 5.54	28. 5.54	21	80 × 30	+4	−1	"Tight"	43·2	290	0·10	0·06	0·04	0·19	Humber	15·2	54·3	0·13	1·2
107	3. 3.54	24. 6.54	113	92 × 33·75	+7	−2·75	"Tight"	97	233	0·39	Nil	0·39	0·34	Severn	13·5	50·6	0·48	7·8
108	3. 3.54	24. 6.54	113	92 × 33·75	+7	−2·75	"Tight"	94	239	0·30	Nil	0·30	0·27	Severn	13·5	50·6	0·41	5·3
109	3. 3.54	24. 6.54	113	92 × 33·75	+7	−2·75	"Tight"	93	271	0·50	Nil	0·50	0·44	Severn	13·5	50·6	0·39	7·1
110	3. 3.54	24. 6.54	113	92 × 33·75	+7	−2·75	Leaking	96	236	0·48	Nil	0·48	0·42	Severn	13·5	50·6	0·45	8·1
111	3. 3.54	24. 6.54	113	92 × 33·75	+7	−2·75	Leaking	86	234	0·48	Nil	0·48	0·42	Severn	13·5	50·6	0·31	5·0
112	30. 3.54	25. 6.54	87	92 × 33·75	+8	−2·5	Leaking	95	210	0·33	Nil	0·33	0·38	Severn	14·1	51·6	0·43	7·4
113	30. 3.54	25. 6.54	87	92 × 33·75	+8	−2·5	Leaking	92	214	0·40	Nil	0·40	0·46	Severn	14·1	51·6	0·37	7·5
114	30. 3.54	25. 6.54	87	92 × 33·75	+8	−2·5	Leaking	92·5	217	0·43	Nil	0·43	0·49	Severn	14·1	51·6	0·38	8·1
115	30. 3.54	25. 6.54	87	92 × 33·75	+8	−2·5	Leaking	95	219	0·74	Nil	0·74	0·85	Severn	14·1	51·6	0·43	15·5
116	30. 3.54	25. 6.54	87	92 × 33·75	+8	−2·5	Leaking	94	217	0·31	Nil	0·31	0·36	Severn	14·1	51·6	0·41	6·35
117	21. 5.54	5. 7.54	45	30 × 30	Free vent		—	44	260	0·79	0·03	0·76	1·69	Tweed	10·7	53·2	0·28	10·3
118	21. 5.54	5. 7.54	45	30 × 30	Free vent		—	70	236	0·41	0·02	0·39	0·87	Tweed	10·7	53·2	0·47	9·9
119	8. 3.54	27. 7.54	141	9 × 30 *	Free vent		—	100	272	0·85	Nil	0·85	0·60	Humber	12·9	51·9	—	—
120	8. 3.54	27. 7.54	141	9 × 30 *	Free vent		—	50	250	1·34	Nil	1·34	0·95	Humber	12·9	51·9	—	—
121	15. 6.54	3. 8.54	49	46 × 35·25	+8	−2·5	"Tight"	5·2	153	0·21	Nil	0·21	0·43	Merseyside	8·4	56·5	0·12	5·0
122	17. 7.54	20. 8.54	34	30 × 30	Free vent		—	56·5	258	0·84	0·04	0·80	2·35	Tweed	11·1	55·3	0·34	17·5
123	17. 7.54	20. 8.54	34	30 × 30	Free vent		—	60	214	0·33	0·03	0·30	0·88	Tweed	11·1	55·3	0·36	8·2
124	23. 3.54	27. 8.54	157	92 × 33·75	+8	−2·5	"Tight"	100	241	0·28	Nil	0·28	0·18	Merseyside	9·5	53·0	0·63	7·4
125	23. 3.54	27. 8.54	157	92 × 33·75	+8	−2·5	Leaking	100	218	0·46	Nil	0·46	0·29	Merseyside	9·5	53·0	0·63	11·3
126	23. 3.54	27. 8.54	157	92 × 33·75	+8	−2·5	Leaking	100	227	0·50	Nil	0·50	0·32	Merseyside	9·5	53·0	0·63	11·8
127	23. 3.54	27. 8.54	157	92 × 33·75	+8	−2·5	Leaking	100	240	0·35	Nil	0·35	0·22	Merseyside	9·5	53·0	0·63	7·8

* Horizontal.

† Approx.

The mean saturation vapour pressure figures refer to saturation at the mean bulk liquid temperature for the test period.

A tank is considered to be full when the liquid level is 1 ft below the eaves. The innage is expressed as a percentage of this tank capacity.

The quantities y and k shown in the last two columns are calculated from the determined thermal breathing losses and test data shown in the table. y is the ratio of the mean effective internal temperature range operative in the tank vapour space, to the mean external temperature range, during the test. k is the ratio of the exposed shell area of the tank, *i.e.* the area of the sides and roof of the tank, to the mean vapour space volume, during the test. The significance of y and k is explained and the correlation between y and k examined in later sections.

y values for leaking tanks are calculated on the assumption that the breather valves have no restraining effect.

INTERPRETATION AND DISCUSSION OF RESULTS

Correlation of Results

It would be expected that the individual losses shown in tabular form in the preceding section are the result of a number of independent variables.

As far as standing tanks are concerned the main variables involved are probably:

External temperature conditions, particularly daily temperature range.
Tank size, shape, and state.
Breather valve settings.
Innage.
Effective vapour pressure.
Duration of test.

In the case of working tanks there is the additional effect of pumping down the tank to be considered, and as this is not directly proportional to the duration of the test a calculated loss due to this cause must first be subtracted from the total loss before the residual loss, which is ascribed to thermal breathing, can be treated as a function of time.

It was realized that to be fully successful the evaporation loss survey must not only present a picture of the losses found under certain given conditions but must also enable losses to be predicted under other conditions, from whatever data would normally be available. The problem was therefore to find some means or formula for linking together the variables covered by the survey, so that a coherent picture would emerge which would allow interpolation between these survey results.

In these circumstances the reasoning was as follows:

(*a*) It is the daily temperature range and daily vapour pressure range in a tank vapour space which causes thermal breathing loss. In the absence of both these effects there would be no breathe from the tank, and hence no loss, ignoring changes in barometric pressure (see page 297).

(*b*) Although one of these effects is in fact a temperature change, whereas the other is a pressure change, they can for convenience be linked together into one term, which is called an effective temperature range inside the tank vapour space.

(*c*) Both the effective temperature range inside the tank and the atmospheric temperature range outside the tank are produced by the same agencies, *e.g.* solar radiation, frost, mass air movement, and therefore it might be expected that these two temperature ranges would be closely related. In fact, taken over a period of time (five or six weeks, say) it might be expected that for a given innage, shape, and size of tank, the ratio of the effective internal temperature range Ri to the external temperature range Re, would be approximately constant.

(*d*) The contents of the tank are heated up or cooled down by the passage of heat through the exposed shell and roof. Therefore, other things being constant, it might be expected that the larger the surface area of the tank, the larger would be the ratio $y = \frac{Ri}{Re}$.

(*e*) Again, the larger the vapour-space volume, the greater must be the amount of heat transferred to effect a given temperature rise or fall, and therefore y should be inversely proportional to the vapour-space volume.

(*f*) Linking (*c*), (*d*), and (*e*) together, it seemed reasonable to suppose that a correlation might exist between $y = \frac{Ri}{Re}$ and k, the ratio of the total shell area of the tank to the vapour-space volume at the given innage. Assuming such a correlation between y and k to exist, and if it could be found from survey data, then it would be possible to predict the effective internal temperature range in a tank from a knowledge of the external temperature conditions, the tank size and innage, from which in turn the breathing loss from the tank could be estimated.

(*g*) Ri is the sum of two quantities, the first of these being the temperature equivalent (Charles Law) of the valve pressure range, and the second quantity the additional internal temperature range which must be assumed in order to explain the thermal breathing loss found solely on the basis of temperature change in the tank vapour space.

To obtain this second quantity the loss must be expressed as a breathe of air–petrol vapour mixture and this volume related to the volume and base temperature of the vapour space, so that its temperature range equivalent can be obtained.

A mathematical treatment along these lines yields the following equation :

$$y = \frac{Ri}{Re} = \left(\frac{\theta T}{408} + \frac{3{\cdot}2\ CeT^2}{NVpf}\right) \Big/ Re$$

where y is the ratio of the mean effective internal temperature range to the mean external temperature range;

Ri is the mean effective internal temperature range;

Re is the mean external temperature range;

C is the tank capacity (taken throughout the experiments as 1 ft less than the height of the tank);

e is the percentage loss in tank capacity due only to thermal breathing;

N is the duration of the test (days);

V is the mean volume of the vapour space measured in the same units as C;

p is the mean vapour pressure of the petrol at the mean bulk storage temperature during the test (mm Hg);

f is a saturation factor (100 per cent saturation of the breathe to bulk liquid conditions would require $f = 1$);

θ is the combined vacuum and pressure range of the breather valves in inches w.g.;

T is the mean bulk storage temperature (° F absolute).

The numerator of this expression (of which the underlying assumptions and derivation are discussed fully in the Appendix) consists of two parts, as explained above. The $\frac{\theta T}{408}$ term is the internal temperature range taken up by the breather valves, while the second term is the additional internal temperature range derived from the measured thermal breathing loss.

A plot of y against k (the ratio of tank surface area to mean vapour space volume during the test) is shown in Fig 2 for all tests on both standing and working tanks where there was no reason from site observations to doubt that the tank in question was in reasonably vapour-tight condition, *i.e.* those tanks described in Table II as " tight."

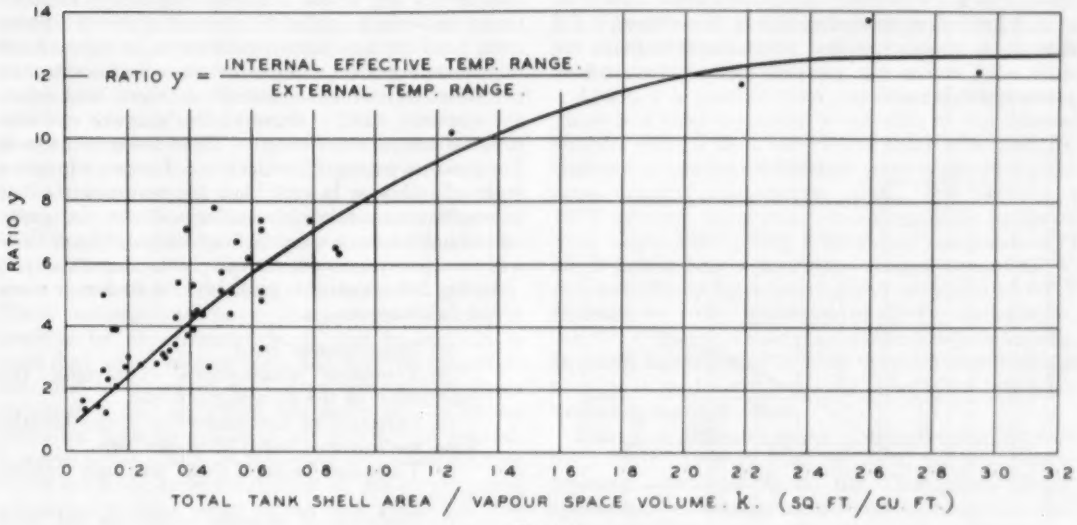
RATIO y = INTERNAL EFFECTIVE TEMP. RANGE. / EXTERNAL TEMP. RANGE.
RATIO y
0
2
4
6
8
10
12
14
0 0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6 1·8 2·0 2·2 2·4 2·6 2·8 3·0 3·2
TOTAL TANK SHELL AREA / VAPOUR SPACE VOLUME. K. (SQ. FT / CU. FT.)

Fig 2

For 1 in 5 cone roof tanks

$$k = \frac{1{\cdot}02 + 4H/Do}{Do/30 + H - I(H-1)}$$

For API tanks

$$k = \frac{1 + 4H/Do}{Do/96 + H - I(H-1)}$$

where Do = tank diameter;
H = tank height;
I = innage (100 per cent innage gives $I = 1$)

In spite of a good deal of scatter, there is clear evidence of a correlation between y and k.

Fig 3 shows a reproduction of the curve only from Fig 2 with the addition of those y values calculated from tests on freely vented or leaking tanks on the assumption that any relief valves present have no restraining effect. Even on this assumption and allowing for experimental error, there is little doubt that some additional effect, probably windage loss, is present in seven or eight tests. (One group of five tanks is painted dark green, and in this case, of course, it is impossible to say whether the additional loss is partially or entirely due to the paintwork.)

Results from 9-ft dia × 30-ft horizontal tanks

cannot be plotted in this manner, as there is no means of assessing the true exposed shell area in these cases. (Attention is directed to the very considerable size of these losses—average figures are 1·9 per cent per annum for a full tank and 3·3 per cent per annum at 50 per cent innage.)

In addition, very small (or zero) losses occurring in the winter months on +8 −2·5 inches w.g. pressure tanks cannot always be plotted because the supposition that each day the valves restrain an amount equivalent to the temperature rise of $\frac{\theta T}{408}$ may not be even a good first approximation in these cases. For the same reason the few measurements made on +20 −2·5 inches w.g. pressure tanks have not been plotted in this manner.

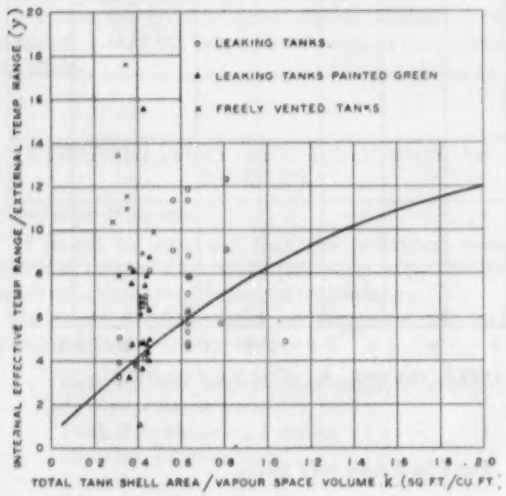
INTERNAL EFFECTIVE TEMP RANGE/EXTERNAL TEMP RANGE (y)
o LEAKING TANKS
▲ LEAKING TANKS PAINTED GREEN
× FREELY VENTED TANKS
TOTAL TANK SHELL AREA/VAPOUR SPACE VOLUME K (SQ FT/CU FT)

FIG 3

The effect of leaks in the tank roof is demonstrated by one group of four tanks covered by the survey. These four adjacent full tanks are of identical construction, fittings, and age, and contain practically the same vapour pressure petrol.

Their states have been assessed as follows:

Tank *A*. Substantially tight—recorder has shown 8 inches w.g. pressure at times.

Tank *B*. Leaking but shows up to 3 or 4 inches w.g. pressure at times.

Tanks *C* and *D*. Leaking but will hold slight pressure.

The losses for the period 19 March 1953 to 27 August 1954 are:

Tank *A*. 0·71 per cent of tank capacity.
Tank *B*. 1·02 per cent of tank capacity.
Tank *C*. 1·07 per cent of tank capacity.
Tank *D*. 1·11 per cent of tank capacity.

From results of the survey as a whole it would be expected that if all these tanks had been "tight" they would each have lost rather over 0·6 per cent of tank capacity in this period of time at this particular place. If no additional effect, *i.e.* windage, were present, the fact that tanks *C* and *D* were working virtually at atmospheric pressure should still have only increased the loss by about 0·12 per cent of tank capacity. The effect found seems to be about three times that amount.

Factors Affecting the Accuracy of Results

Figs 2 and 3 both show a considerable scatter. In the case of Fig 3 this is hardly surprising, as these tanks are almost certainly in various states of "leakiness," and the assumption that the relief valves have no restraining effect will in some cases be too extreme, *i.e.* there will be some restraining effect, and hence a lower loss, with a correspondingly lower effective internal temperature range. These cases will therefore produce points below the line. In cases where the state of leakiness is such that the restraining effect is small or non-existent, windage effects can cause additional losses of varying magnitude. These cases will therefore produce scattered points above the line.

In Fig 2 the scatter is probably due to one or more of the following causes:

(*a*) Experimental error.

(*b*) Erroneous assumptions concerning the calculation of the pumping-out loss.

(*c*) Variation of the saturation of the breathe from the assumed value of 80 per cent.

(*d*) Unknown leakage from the tank vapour space.

(*e*) Variation in climatic conditions not fully covered by the external temperature range criterion.

(*f*) Incorrect assessment of true mean vapour pressure at storage temperature.

Experimental error produces the largest effect in measurements from full, or nearly full, standing storage tanks. The main source of the experimental error lies in the sampling rather than in the Chenicek–Whitman apparatus, *i.e.* the difference between two supposedly identical samples is very much greater than the difference between two determinations of the same sample. The overall error for a complete loss determination is about ±1 mmHg, which corresponds to ±0·04 per cent of tank capacity. Thus, for a measured loss returned as 0·10 per cent it would be expected that the actual loss is somewhere between 0·06 and 0·14 per cent of tank capacity, whereas for a measured loss of 1 per cent the actual loss will be somewhere between 0·96 and 1·04 per cent.

Thus, the percentage error in any loss measurement depends on the magnitude of the loss, being greater, the smaller the loss. Each of the forty-seven points plotted in Fig 2 has a particular percentage error associated with it, but in order to give a rough guide to the extent of inaccuracy present, the points may be grouped as follows:

Of the forty-seven points plotted in Fig 2, twenty-

two were measurements on standing storage tanks with innages of 90 per cent or more.

Of these twenty-two points, twelve gave loss measurements of from 0·06 to 0·20 per cent of tank capacity, and it would be expected that these twelve measurements would therefore be subject, on average, to an error in the region of ±30 per cent.

The remaining ten points gave loss measurements of from 0·21 to 0·50 per cent of tank capacity, and are therefore subject, on average, to an error of about ±12 per cent.

The remaining twenty-five points on Fig 2 were measurements either on standing storage tanks at low innages or on working tanks, and in these cases the vapour pressure change to be measured was sufficiently large for the effect of experimental error to be comparatively small. These twenty-five measurements can be expected to be subject, on average, to an error of about ±3 per cent.

In all cases errors should be of a random nature and produce scatter rather than systematic error.

With working tanks assumptions must be made to relate the measured vapour pressure change with a given percentage loss from the tank in question. These assumptions have been checked wherever possible by experimental work, and in addition a good deal of calculation work has been performed to see what is the effect on the percentage loss figure obtained if various errors are made in the values taken for those quantities in any doubt. In general, it is true to say that from this cause only small random errors are to be expected, except in one or two cases where the working down of the tank under test has been very irregular and more than the normal uncertainty exists as to the changes of vapour pressure occurring in the vapour space.

y values obtained from standing storage tests, and from tests on tanks where the working down was insufficient to have any appreciable effect, have been compared with y values obtained from tests made on normal working tanks; each group gives about the same ratio of points above the correlation line to points below the line.

This again suggests that errors under headings (*b*) and (*c*) produce scatter and not systematic error.

In calculating y values, 80 per cent saturation of the breathe to bulk liquid storage temperature has been assumed, this figure being based on Orsat measurements made by the authors. It is, of course, unlikely that the breathe from a tank will always be saturated exactly to 80 per cent; in fact, the saturation value of the breathe from a tank on a given day must be dependent on a large number of variables. What is suggested is rather that 80 per cent saturation is a suitable value to apply to the tests made, as a whole. It might be expected that in some tests the true mean value over the test period will deviate from the 80 per cent assumed. Such deviations will produce scatter.

Errors due to cause (*d*) are difficult to assess. When sampling the various tanks under test an attempt has been made, by examining the more obvious points where leaks are likely to develop, by generally noting whether the tank is holding pressure in circumstances where pressure would be expected, and in some cases by fitting pressure recorders to the tanks, to ascertain the true state of the tank. It is, however, never possible from such observations to be absolutely certain that no leaks are present, and in addition that manhole covers, dip hatches, etc., have been firmly secured during the whole test period. To take an extreme case, a tank standing for one or two days with a manhole cover removed when the innage is low would result in a large vapour-pressure change in the residual liquid and a correspondingly large error in the loss determination.

Again, it is unlikely that the external temperature range is a fully satisfactory criterion of the internal thermal conditions in the vapour space of a tank, *i.e.* there are a number of different ways of producing the same external temperature range. For instance, a 15° F external temperature range could be produced by a slight frost giving a minimum temperature of 30° F followed by a maximum temperature of 45° F, or alternatively by a warm night minimum of 60° F followed by a day maximum of 75° F. In addition, the 15° F rise could take place either slowly or rapidly. It would be surprising if these very different climatic conditions produced always the same effect inside the vapour space of the tank.

Finally, a difficulty arises in determining the true mean vapour pressure from the initial and final vapour pressures obtained from the Chenicek–Whitman apparatus. Normally the arithmetic mean has been taken as an adequate representation of the true mean, but in a few cases where the change in vapour pressure was abnormally large the logarithmic mean has been taken as a better representation of the true mean, as it is normal to find a practically linear relationship between the logarithm of the vapour pressure of a petrol and the percentage distilled from the spirit. This procedure cannot, however, be perfect, and some small error must be expected from this cause.

METHOD OF USING THE SURVEY RESULTS TO PREDICT LOSSES

Quite obviously, it is possible by using the correlation formula shown earlier to calculate the loss from any given tank for any short period of time (six weeks or two months, say) provided the climatic conditions, breather valve settings, innage, etc. are known; this being done, of course, by using the formula in reverse, *i.e.* previously y was obtained from known values of V, c, e, etc., whereas y is now obtained from the correlation curve from the known value of k, and then e from this y value, and the known values of c, P, N, etc.

This procedure has the merit that systematic errors resulting from any incorrect assumptions made in obtaining the correlation between y and k are practic-

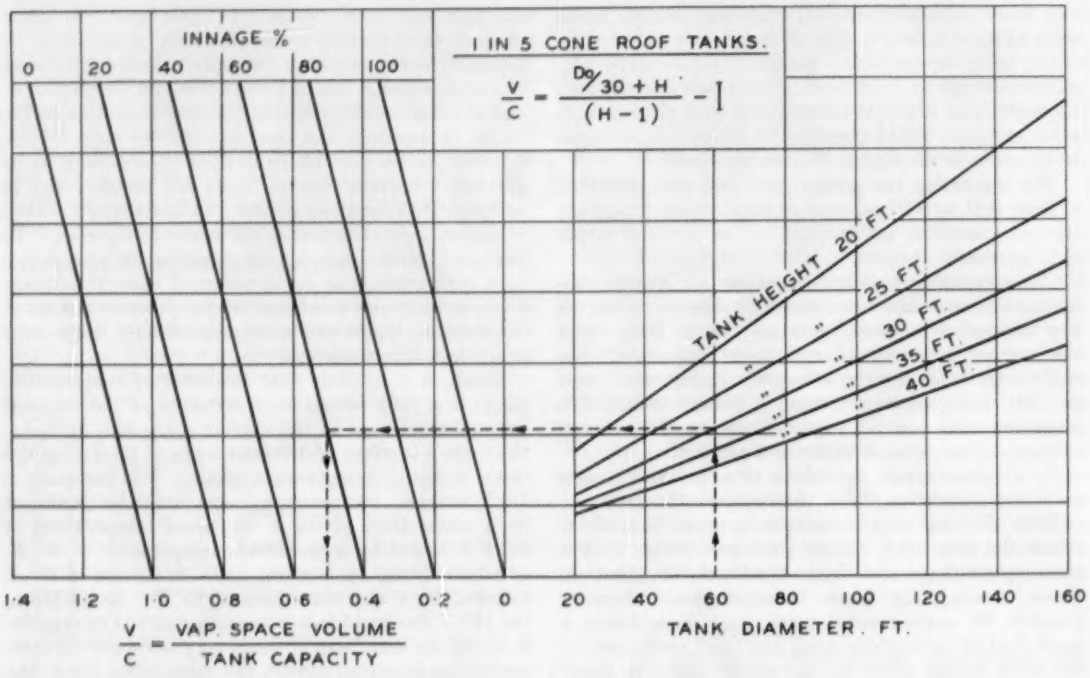
INNAGE %
0
20
40
60
80
100
1 IN 5 CONE ROOF TANKS.
V/C = Dg/30 + H / (H − 1) − 1
TANK HEIGHT 20 FT.
" 25 FT.
" 30 FT.
" 35 FT.
" 40 FT.
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
20
40
60
80
100
120
140
160
V/C = VAP. SPACE VOLUME / TANK CAPACITY
TANK DIAMETER. FT.

Fig 4

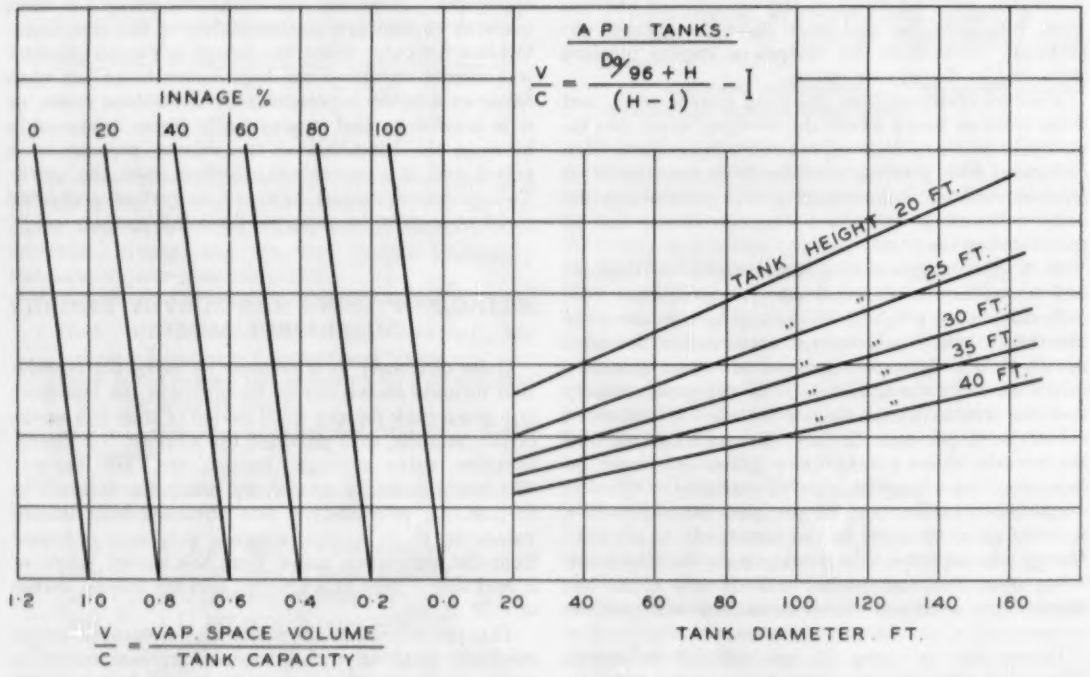
A P I TANKS.
V/C = Dg/96 + H / (H − 1) − 1
INNAGE %
0
20
40
60
80
100
TANK HEIGHT 20 FT.
" 25 FT.
" 30 FT.
" 35 FT.
" 40 FT.
1·2
1·0
0·8
0·6
0·4
0·2
0·0
20
40
60
80
100
120
140
160
V/C = VAP. SPACE VOLUME / TANK CAPACITY
TANK DIAMETER. FT.

Fig 5

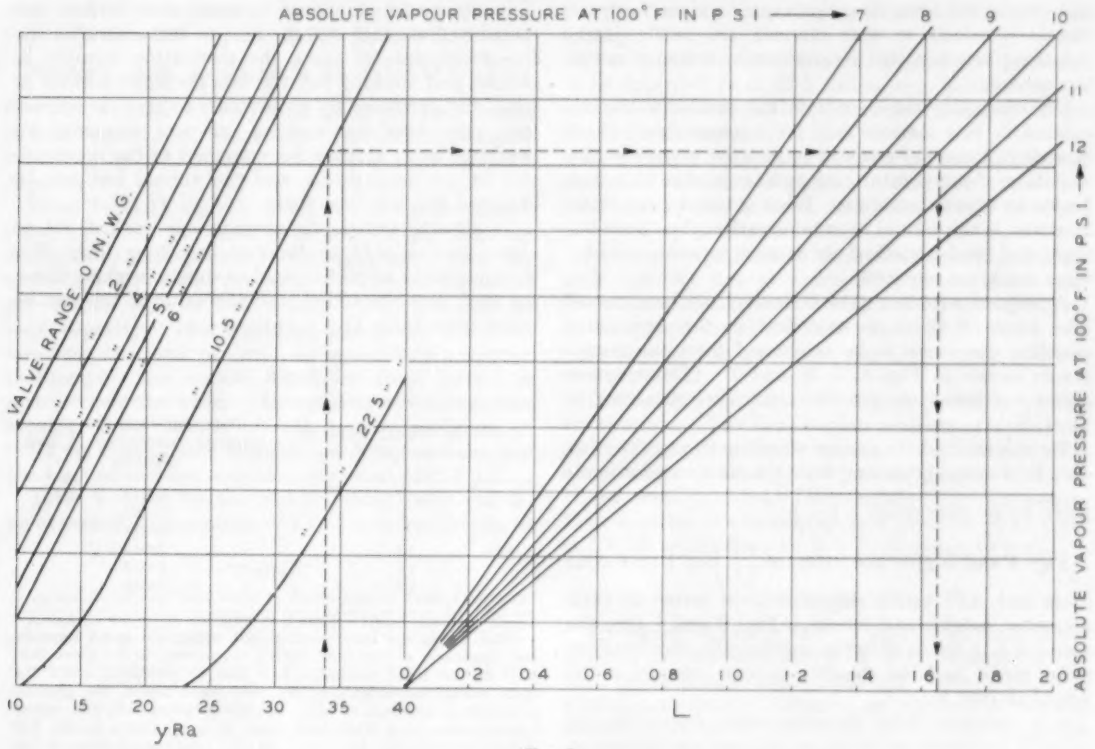
ABSOLUTE VAPOUR PRESSURE AT 100° F IN P S I
7
8
9
10
11
12
VALVE RANGE 0 IN W G
2 " " "
4 " " "
5 " " "
6 " " "
10·5 " " "
22·5 " " "
ABSOLUTE VAPOUR PRESSURE AT 100° F. IN P S I
0 0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6 1·8 2·0
L
10 15 20 25 30 35 40
yRa

FIG 6

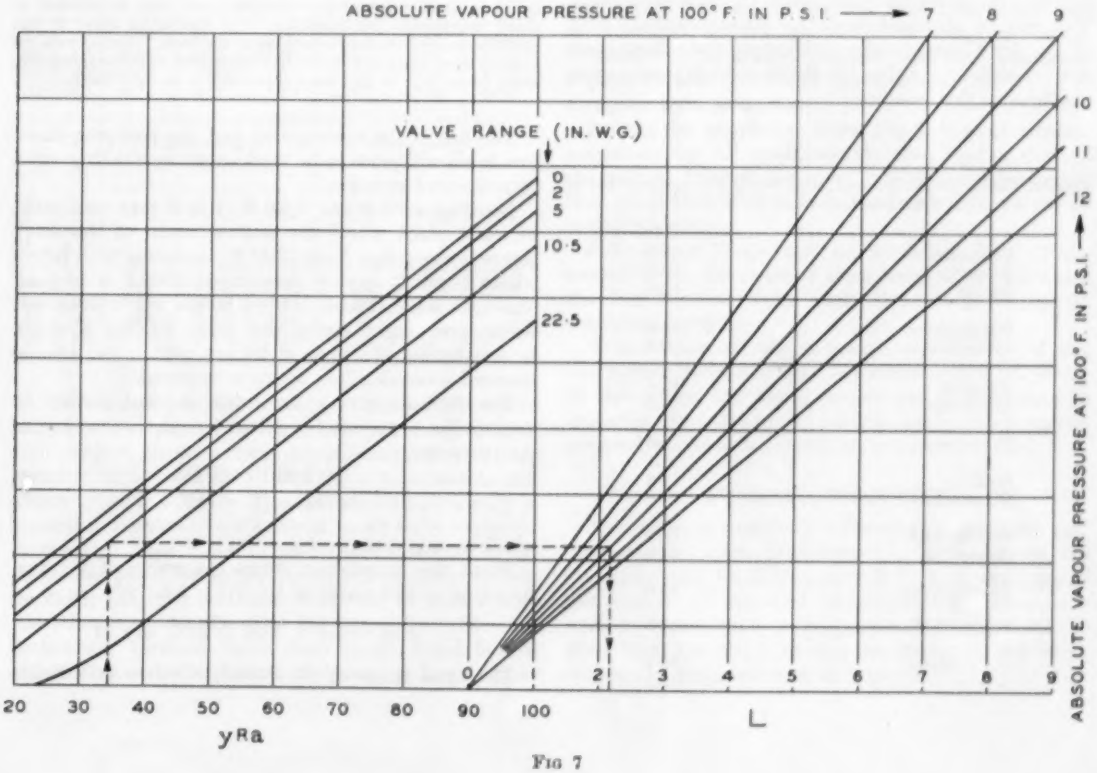
ABSOLUTE VAPOUR PRESSURE AT 100° F. IN P S I
7
8
9
10
11
12
VALVE RANGE (IN. W G)
0
2
5
10·5
22·5
ABSOLUTE VAPOUR PRESSURE AT 100° F. IN P.S.I.
0 1 2 3 4 5 6 7 8 9
L
20 30 40 50 60 70 80 90 100
yRa

FIG 7

ally eliminated from the calculations and, in fact, the results obtained in this manner are really interpolations between the determinations carried out in the survey.

Unfortunately the loss from the tank can be calculated in this manner only for comparatively short periods of time, say one or two months, otherwise the variation of temperature range from season to season begins to affect the result. What is usually required, however, is the annual thermal breathing loss from the tank, and by this method six or more separate calculations would be required.

A way of avoiding this difficulty has been found (the basis of which is described in the Appendix) enabling the losses to be calculated from the nomograms shown in Figs 4, 5, 6, and 7. (These nomograms are based on climatic conditions obtaining in the U.K.)

By this method the annual standing storage loss due only to thermal breathing from the tank in question is given by an expression $L\left(\frac{V}{C}\right)$.

Figs 4 and 5 give the value of $\left(\frac{V}{C}\right)$ for 1 in 5 cone roofs and API tanks respectively in terms of tank diameter, height, and innage. Figs 6 and 7 give the value of L in terms of the quantities yRa, the breather valve range, and the absolute vapour pressure of the petrol at 100° F.

y is obtained from the correlation curve for the value of k worked out from the appropriate expression shown on p. 305. Ra is the annual mean daily temperature range for the place where the tank is situated. This can be obtained from the Meteorological Office of the Air Ministry, who will supply data from their nearest station. Table III shows some typical values obtained in this manner:

TABLE III

Typical Values for the Annual Mean Daily Temperature Range at Oil Storage Areas in the U.K.

	(° F)
Plymouth	10·9
Bristol	13·9
Cardiff	12·4
Birmingham	11·6
Liverpool	9·9
Glasgow	12·5
Edinburgh	13·3
Tynemouth	8·6
Hull	12·6
Hunstanton	11·9
Westminster	12·9
Greenwich	14·8
Southampton	14·0
Foynes (Ireland)	11·8
Mean	12·2

One point which should be made clear is that this method of working out the results still embodies the sound principle of using the correlation formula in reverse and working out the loss for short periods of time, and summing up those losses to give the annual loss, only now the working out and summing up processes have already been applied in the construction of the nomograms, and the annual loss can be obtained directly from them.

As already stated, the storage loss worked out as above is due only to thermal breathing loss. For working tanks an additional loss due to working down the tank must be added, and the value of this can be taken from Table IV.

TABLE IV

Absolute vapour pressure of petrol at 100° F, p.s.i.	Pumping-down loss per turnover, percentage of tank capacity
7	0·018
8	0·025
9	0·034
10	0·044
11	0·055
12	0·068

This Table has been worked out using the same formulæ and approach as was used during the survey to calculate that part of the total measured loss due to pumping down the tank under investigation, so that here again the general principle of reversal of error applies. Specifically the calculations refer to a 30-ft high tank pumped down in six 5-ft drops at seven-day intervals, but by trial calculations it has been found that the values obtained do not vary very much with: (*a*) tank dimensions; (*b*) rate of working over the range three to twelve turnovers per year; and (*c*) amount of stock transferred per operation over the range three to ten operations per complete emptying of the tank. For operations outside these ranges it would be anticipated that the pumping-down losses will be less than those shown in this Table.

The use of the nomograms and the pumping-down loss table will perhaps be made clear by working out a hypothetical example.

Consider a 60 ft dia × 30 ft, 1 in 5 cone roof tank, in some place where the annual mean of the daily temperature range Ra is 13·5° F, operating with petrol whose absolute vapour pressure at 100° F is 10 p.s.i. The tank is fitted with +4 −1 inches w.g. valves, and turns over eight times per year, having a mean innage during the year of 60 per cent. The annual thermal breathing loss figure is required.

The formula giving the ratio of total surface to vapour-space volume for a 1 in 5 cone roof tank is as shown earlier,

$$k = \frac{1{\cdot}02 + 4H/Do}{Do/30 + H - I(H-1)}$$

which in this case gives $k = 0{\cdot}21$.

From the correlation curve the value of y corresponding to this value of $k(0{\cdot}21)$ is 2·5.

$$\therefore \quad yRa = 2{\cdot}5 \times 13{\cdot}5 = 33{\cdot}7, \text{ say } 34.$$

The total range of the breather valves is 5 inches

w.g. ∴ from nomogram 7 for $\theta = 5$, $yRa = 34$, and vapour pressure of 10 p.s.i. at 100° F, $L = 2{\cdot}16$.

Similarly, from nomogram 4 the value of $\left(\frac{V}{C}\right)$ for 60 × 30, 1 in 5 cone roof tank at 60 per cent innage is 0·51 approx. ∴ The annual loss due to thermal breathing is 2·61 × 0·51 = 1·10 per cent of tank capacity.

From Table IV the calculated additional loss due to pumping down the tank once is 0·044 per cent for absolute 10 p.s.i. petrol, ∴ for eight turn-overs this extra loss will be 0·35 per cent. ∴ The combined loss per annum will be 1·10 + 0·35 = 1·45 per cent of tank capacity. This combined loss is not the total loss from the tank per year, as in addition a further pumping-in loss occurs whenever fresh petrol is pumped into the tank. (As a matter of interest, this average filling loss is estimated as a minimum of 0·012 per cent of tank capacity per complete turnover per p.s.i. of absolute vapour pressure at 100° F.)

Table V shows the thermal breathing losses only to be expected from a range of 1 in 5 cone roof tanks at

TABLE V

Thermal Breathing Loss Only in Percentage of Tank Capacity

Absolute 10 p.s.i. at 100° F Petrol. Mean Annual Temperature Range 12·2° F. 1 in 5 Cone Roof Tanks.

	Valve range—negligible			Valve range—5 inches w.g.		
Innage : Tank size, $d \times h$ ft	95%	60%	5%	95%	60%	5%
30 × 30	1·22	1·74	2·06	1·15	1·51	1·58
60 × 30	0·93	1·21	1·52	0·85	0·97	1·01
80 × 30	0·85	1·06	1·39	0·76	0·81	0·88
120 × 35	0·77	0·98	1·21	0·57	0·62	0·68
	Valve range—10·5 inches w.g.			Valve range—22·5 inches w.g.		
Innage : Tank size, $d \times h$ ft	95%	60%	5%	95%	60%	5%
30 × 30	1·09	1·28	0·81	0·95	0·73	0·05
60 × 30	0·78	0·69	0·44	0·59	0·17	Nil
80 × 30	0·66	0·52	0·32			
120 × 35	0·47	0·37	0·16			

95, 60, and 5 per cent innages with various valve ranges when storing a 10 p.s.i. petrol at 100° F and subject to an annual mean daily temperature range of 12·2, calculated from the nomograms in the above manner. Table V is intended to give only a general indication of the order of losses to be expected in the U.K., the value of $Re = 12{\cdot}2$ referring to no particular place, being the mean of those places shown in Table III. In addition, it should be noted that less reliance can be placed on the figures for +20 −2·5 inches w.g. pressure tanks than on the other figures shown, because the former represent a large extrapolation from the data obtained on the lower pressure settings.

It is hoped that a more reliable guide to the losses to be expected from 22·5 inches w.g. pressure range tanks will be obtained in the near future by direct tests on such tanks.

In principle, the same applies to the figures for negligible valve loadings, but in this case the extrapolation involved is small, and reliance can therefore be placed upon these results.

As a matter of interest the mean percentage loss in tank capacity due to combined pumping down and thermal breathing found during the survey taking all tanks except horizontal 9-ft dia × 30-ft tanks and regardless of valve settings, state, etc., was 1·29 per cent per year.

Throughout this paper all vapour pressures quoted are absolute. The Reid vapour pressure of a petrol of given absolute vapour pressure depends on the composition of that petrol but in general is about 10 per cent lower than the absolute vapour pressure. Thus a petrol of absolute vapour pressure of 11 p.s.i. at 100° F would have an R.V.P. of about 10 p.s.i.

CONCLUSIONS

The figures shown in Table V give an estimate of the order of thermal breathing loss to be expected in the U.K. under good storage conditions. The nomograms provide a method of obtaining an estimate of thermal breathing losses in the U.K. for a wide range of conditions, from known data.

The figures confirm Sarjeant's[3] finding that a worthwhile decrease in thermal breathing losses can be achieved by the provision of suitably loaded breather valves, always provided that due attention is given to maintenance of the tank and its fittings in a vapour-tight condition.

It may be concluded from Fig 3 that if storage conditions are not good, *e.g.* the tank roof or fittings are leaking, the loss can in an extreme case be double that predicted for a tight tank fitted with valves of negligible loading.

Still larger losses can be expected from freely vented tanks, the order of these being about 2·5 times the loss from a tight tank fitted with valves of negligible loading.

A discussion of the economic significance of the loss figures presented does not come within the scope of this paper, but these figures are of assistance in assessing the value of the various means which can be adopted to reduce or eliminate evaporation loss.

ACKNOWLEDGMENTS

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APPENDIX

THE MATHEMATICAL BASIS OF THE SURVEY

As explained previously the Chenicek–Whitman method of evaporation loss measurement depends upon the measurement of the drop in vapour pressure of the petrol in a tank coupled with a measurement of the percentage which must be evaporated from a sample of that petrol to cause that vapour pressure drop.

In a working tank this percentage drop caused by evaporation is due to: (*a*) evaporation into the increased vapour space of the tank which results from working down the tank; (*b*) pumping-down loss; (*c*) thermal breathing loss.

It is impossible to measure these three effects separately by observations either of the quantity or quality of the petrol in the tank because these effects often occur together; what can be obtained is a measurement of the combined effect of all three, and calculation of two of the effects gives the third by difference. In general, when faced with such circumstances, if it is thought that any two of the three effects can be calculated with the same percentage error in each, one would always choose to calculate the two smallest effects, as this minimizes the percentage error in the larger portion, which is determined by difference. In this particular case not only are effects (*a*) and (*b*) usually smaller than effect (*c*) but in addition it is possible to calculate effects (*a*) and (*b*) with considerably greater accuracy than could be obtained with a calculation of the thermal breathing loss. For these reasons (*a*) and (*b*) have been calculated and (*c*) determined by difference.

The Change in the Final Sample caused by Transfer of Petrol from Liquid to Vapour Phase

Consider a tank of cross-section A sq. ft. which, following a pumping-down operation, contains h ft of petrol. Suppose that immediately after this operation the mean vapour pressure of the vapour space is p_i mm Hg and that subsequently during the period of standing at this level the vapour pressure rises to p_f mm Hg. As the cross-section is constant, the vapour space volume can be expressed as V linear ft, *i.e.* an actual volume of VA cu. ft. (This is a convenient form of expression because the volume of the cone roof portion can easily be expressed as linear feet. For a 1 in 5 cone roof the height of the cone is $\frac{Do}{10}$ and the volume of the cone is $\frac{Do}{30}$ linear ft of cross-section A sq. ft.) If the average absolute temperature and pressure in the vapour space throughout the period is $T°$ F absolute and P mm Hg, the initial petrol content will be $\frac{p_i VA}{P}$ cu. ft. expressed at pressure P and temperature T, the final petrol content will be $\frac{p_f VA}{P}$ cu. ft. under the same conditions and the increase in the petrol content $= \frac{VA}{P}(p_f - p_i)$ cu. ft. at temperature T and pressure P. The increase in petrol content at N.T.P. is

$$\frac{VA}{P}(p_f - p_i) \times \frac{P}{760} \times \frac{492}{T} = \frac{VA}{760}(p - p_i) \times \frac{492}{T}$$

If M is the molecular weight of the petrol evaporate, the weight of petrol transferred from liquid to vapour phase

$$= \frac{VA}{760}(p_f - p_i) \times \frac{492}{T} \times \frac{M}{359} \text{ lb.}$$

(1 lb mol of gas occupies 359 cu. ft. at N.T.P.)

If D is the density of the evaporate in lb/I.G. the volume lost from the liquid

$$= \frac{492\ VAM\ (p_f - p_i)}{TD \times 760 \times 359 \times 6{\cdot}23} \text{ cu. ft.}$$

$\therefore$ the percentage loss in the petrol due to this transfer

$$= \frac{49200\ VAM(p_f - p_i)}{ThAD \times 760 \times 359 \times 6{\cdot}23}$$

$$= 0{\cdot}588 \times 10^{-4} \times \left(\frac{M}{D}\right)\frac{V}{h}(p_f - p_i)\frac{492}{T}$$

The value of $\frac{M}{D}$ can be found from the Chenicek–Whitman determinations, but for normal petrol varies very little from 10·8. Using this value, the percentage loss in the petrol caused by the transfer of petrol to the vapour space is $6{\cdot}35 \times 10^{-4} \times \frac{V}{h}(p_f - p_i)\frac{492}{T}$. The total change in the end sample caused by this effect when working down the tank is, of course, the sum of the percentage changes at each such stage as the above.

The use of the equation above demands a knowledge of the change of vapour pressure $(p_f - p_i)$ occurring in the vapour space of the tank following a pumping-down operation.

A good indication of this change can be derived from a curve obtained by Happel and Heath. This curve, which is reproduced in Fig 8, shows the change in saturation referred to a temperature just below the liquid surface, which took place in a 25-ft dia × 25 ft cone roof tank pumped down very rapidly from an initial innage of approximately 23·5 ft to a final innage of approximately 5 ft.

It has been applied here as showing the degree of saturation referred to bulk liquid temperature instead of to liquid surface temperature, but compensation is obtained by omitting the $\frac{492}{T}$ correcting term.

Happel and Heath take a similar step with a similar equation which they have derived, and have found from a number of tests they have made that this procedure is satisfactory. The correction is in any case not large.

The authors have twice checked the Happel and Heath curve in rather different circumstances, the results being as follows :

In the first experiment an 80 ft dia × 30 ft tank which had stood for a week at an innage of 22·5 ft approx was subject to a small pumping down, 2·75 ft approx of the liquid being removed. Pumping ceased at about 5 p.m., at which time the distribution of vapour was uneven, the vapour pressure at the top of the tank being very small indeed. By 11 a.m. the next morning the vapour pressure in the whole vapour space had returned practically to its original value and the vapour distribution was once more even.

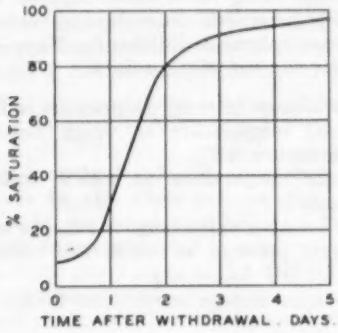

FIG 8

Further very small increases in mean vapour content occurred during the following days. The overall rate of rise in saturation was considerably higher than the Happel and Heath curve would have predicted.

In a second experiment 6·7 ft of petrol was pumped into each of two previously vapour-freed 50 ft dia × 30 ft tanks both connected to a vapour sphere. In both cases the overall rate of rise of vapour pressure was somewhat slower than the Happel and Heath rate. The mean saturation vapour pressure *vs* time curves obtained were similar in form to the Happel and Heath curve. In view of this similarity in form, and also because the Happel and Heath curve was a fair representation of the mean rate of approach to saturation averaged over the authors' three tests, this curve was used in the estimation of losses connected with pumping-down operations.

The curve is applied in the following manner :

Suppose that when a given tank is first filled and the initial sample is taken the volume of the vapour space is V_1 cu. ft. After the first pumping down let the vapour space increase to V_2 cu. ft. Then if p is the vapour pressure of the liquid at its mean bulk storage temperature for the test, assuming that the vapour space is initially saturated to this temperature, which is almost certain to be true, the mean vapour pressure immediately after pumping down will be $(p_i)_1 = p\left(\frac{V_1}{V_2}\right)$ and percentage saturation $\frac{100V_1}{V_2} = S_1$. The value of $(p_f)_1$ after n days, *i.e.* immediately before the next pumping down, is now required. Starting on the curve at the point where the saturation is S_1, move along the time axis $n - \frac{1}{2}$ days and read off the saturation S_2. Then $(p_f)_1 = p \times \frac{S_2}{100}$. ($n - \frac{1}{2}$ is used instead of n to allow for the delay of one-half day approx which is apparent at the bottom of the Happel and Heath curve, and also to a lesser extent in our own second experiment, which seems to be required to allow the stirring in the vapour space to become thoroughly established.) From this value of $(p_f)_1$ the value of $(p_i)_2$ after the next pumping down is calculated

$$(p_i)_2 = (p_f)_1 \times \frac{V_2}{V_3} \text{ and so on.}$$

This method of calculation may seem rather arbitrary and unlikely to give persistently accurate results. To some extent this is true, and probably is one of the reasons for the scatter of some of the points about the correlation curve. Fortunately, however, for the most part circumstances have been such that the error should be confined to reasonable limits.

First, in the survey the working tanks have for the most part worked down reasonably regularly in drops of several feet with three or more days in between most of the drops. The result of this is that while in most drops the p_i value is somewhere on the steep portion of the curve, p_f is on the flatter portion, where the rate of rise of vapour pressure is low and where any error in the estimate of S_2 should be small. In this case a large error in the estimate of $(p_f - p_i)$ would not be expected. Where, as has occasionally happened, the time intervals between transfers from the tank have been small an accurate estimate of $(p_f - p_i)$ is not so likely.

Secondly, taking a typical working tank starting with an innage of, say, 28 ft, and working down to a final innage of, say, 1 to 2 ft, the measured total loss from the end sample would be, say, 2·0 per cent, of which, say, 0·5 per cent is ascribed to transfer of petrol from the liquid to the vapour space resulting through working down the tank. An error of 10 per cent in the calculation of the percentage loss in the end sample due to transfer to the vapour phase gives only a 3·3 per cent error in the estimate of the residual portion due to thermal breathing and pumping-down loss.

Calculation of Combined Loss expressed in Percentage Tank Capacity

The foregoing paragraphs show a method of correcting the percentage change found in the end sample to allow for that part of this measured change which is due to transfer of petrol from the liquid to the vapour phase. The residual amount E per cent, due to pumping down and thermal breathing losses occurring at the various liquid levels at which the tank has stood, must now be converted into a loss in tank capacity as follows :

Consider a tank height H and cross-section A sq. ft. which suffers losses Z_1, Z_2, Z_3, . . . etc., linear ft of

petrol vapour (referred to convenient conditions of temperature and pressure) from petrol depths h_1, h_2, h_3, . . . etc. Loss Z_1 linear ft of petrol vapour = aZ_1A cu. ft. of liquid petrol, where a is a constant. The percentage change resulting in the h_1 ft of petrol present when the loss Z_1 occurred

$$= \frac{aZ_1A\ 100}{h_1A} = \frac{100\ aZ_1}{h_1}$$

This change will be present in the final sample. Similarly, the percentage change at the h_2 level from breathe Z_2 is $\frac{100\ aZ_2}{h_2}$. On these lines the final sample will have a total percentage change of

$$100\ a\left(\frac{Z_1}{h_1} + \frac{Z_2}{h_2} + \frac{Z_3}{h_3} \ldots\right) = E,$$

which is the change determined by the Chenicek–Whitman apparatus after correction for transfer of petrol to the vapour space. The actual losses, however, $aA(Z_1 + Z_2 + Z_3 \ldots)$ cu. ft. of liquid petrol, $\therefore$ substituting for a, the total loss in cu. ft. of liquid

$$= \frac{AE}{100}\left(\frac{Z_1 + Z_2 + Z_3 \ldots}{\frac{Z_1}{h_1} + \frac{Z_2}{h_2} + \frac{Z_3}{h_3} \ldots}\right)$$

$$= \frac{AE}{100}\frac{\Sigma Z}{\Sigma \frac{Z}{h}}$$

Taking the tank capacity as 1 ft down from the tank eaves (which has been done throughout the survey), the percentage loss in tank capacity

$$= \frac{100}{(H-1)A} \times \frac{AE}{100} \times \frac{\Sigma Z}{\Sigma \frac{Z}{h}}$$

$$= \frac{E}{(H-1)} \times \frac{\Sigma Z}{\Sigma \frac{Z}{h}} = Q$$

The Z terms can now be divided out into pumping-down losses G_1, G_2, G_3, etc., and thermal breathing losses Y_1, Y_2, Y_3, etc., *i.e.* Q the percentage loss of tank capacity

$$= \frac{E\ (\Sigma Y + \Sigma G)}{(H-1)\left(\Sigma \frac{Y}{h} + \Sigma \frac{G}{h}\right)}$$

The form of the expression above is of importance. Because the Y and G terms occur both in the numerator and denominator of the expression it is possible to use approximate estimations of each and yet obtain an accurate final value for Q. (This has been checked numerically on a number of occasions.) The value of Q is, in fact, dominated by the size of the vapour pressure change found in the final sample and the various levels h_1, h_2, h_3, etc., at which the tank has stood during the test. The next two subsections describe the methods by which the thermal breathing loss and pumping-down loss terms can be estimated.

The Estimation of Thermal Breathing Loss Y Terms

To estimate the breathing losses Y_1, Y_2, etc., it is necessary to make some assumptions about the variables involved—it is in fact assumed that the loss at each stage is proportional to :

(*a*) the number of days standing at that level;
(*b*) the mean vapour pressure in the vapour space during the period;
(*c*) the volume of the vapour space during the period; and
(*d*) the internal temperature range above that of the breather valve restraint during the period.

Proceeding along these lines, suppose the petrol stands at a given level for n days in contact with a vapour-space volume of V linear ft. Suppose that on a particular day out of the n days,

the minimum internal temperature is T_1;
internal temperature at which breathing out commences is T_2;
internal temperature at which breathing out ceases is T_3;
total breather valve range is θ inches w.g.;
absolute pressure at which the vacuum valve closes is P inches w.g.;
bulk liquid storage temperature for the test is T.

Applying the gas laws,

$$\frac{VP}{T_1} = \frac{V(P+\theta)}{T_2}$$

$$\therefore\ T_2 = \left(\frac{P+\theta}{P}\right)T_1 = \left(1 + \frac{\theta}{P}\right)T_1$$

Now if v is the volume loss in linear feet from the tank due to the temperature rise T_2 to T_3, then

$$\frac{V(P+\theta)}{T_2} = \frac{(v+V)(P+\theta)}{T_3}$$

$$\therefore\ v = \frac{V(T_3 - T_2)}{T_2}$$

at temperature T_3 and pressure $(P+\theta)$. This corrected to temperature T and pressure P

$$= v_1 = \frac{V(T_3 - T_2)}{T_2} \times \frac{T}{T_3} \times \left(\frac{P+\theta}{P}\right)$$

linear ft at T and P, but previously

$$PT_2 = (P+\theta)T_1$$

$$\therefore\ v_1 = \frac{V(T_3 - T_2)}{T_1} \times \frac{T}{T_3}$$

If the internal effective temperature range is $Ri = bRe$ for the day under consideration then $T_3 = T_1 + bRe$

and $$v_1 = \frac{VT}{T_1T_3}\left(T_1 + bRe - T_1 - \frac{\theta}{P}T_1\right)$$

$$= \frac{VT}{T_3}\left(\frac{bRe}{T_1} - \frac{\theta}{P}\right)$$

Normally T_1 may be one or two degrees less than T the bulk liquid storage temperature, while T_3 will be several degrees above T, but for the purposes of developing an approximate breathe expression it is sufficiently accurate to take both T_1 and T_3 as equal to T and P as equal to 408 inches w.g.

Hence, $$v_1 = \frac{V}{T}\left(bRe - \frac{\theta T}{408}\right) \text{ linear ft}$$

at temperature T and pressure 408 inches w.g., and the breathe for the whole n day period will be

$$\Sigma v_1 = \frac{V}{T}\,\Sigma\left(bRe - \frac{\theta T}{408}\right)$$

If the mean vapour pressure for the n days is p_a mm Hg, then the loss in linear feet of petrol vapour at temperature T and normal pressure,

$$Y = \frac{p_a V}{760T}\,\Sigma\left(bRe - \frac{\theta T}{408}\right) \text{ linear ft}$$

From this formula Y_1, Y_2, Y_3 at levels h_1, h_2, h_3 are worked out for the whole test period. b has been given the arbitrary constant value of 1·5, but repeated calculations have shown that in nearly every case the constant value given to b can be doubled or trebled without any significant change in the end result (because of the form of the expression in which the Y terms are applied). It might be anticipated that b $\left(\text{which is } \frac{Ri}{Re}\right)$ would, in fact, vary with innage, because when the tank is full the ratio of heating surface area to vapour-space volume is greater than when the tank is nearly empty; thus when the tank is full a larger value of Ri would be expected for a given value of Re than when the tank is empty. If one applies some arbitrary variation in b (making, say, $b = 3$ when the tank is full, 2 when the tank is half-full, and 1 when the tank is nearly empty) the end percentage loss in tank capacity given by this treatment is always rather larger than the percentage returned by assigning an arbitrary constant value to b. Clearly, the true values of b are not known and in these circumstances it is better to use the constant value knowing that this, if it errs at all, will give an underestimation of the loss.

Calculation of Pumping-down Breathe, G Terms

In the following treatment of the pumping-down loss calculation the variation in pressure in the tank due to the presence of breather valves is ignored, it being reasoned that in general the valve range is fully taken up in dealing with thermal expansion, and can therefore have little effect on the pumping-down loss. The exact effect caused by the superimposition of the thermal changes occurring daily in a tank upon the slower vapour pressure changes resulting from the pumping-down process depends on a great many variables and is difficult to follow mathematically. Calculation suggests that the simplified approach shown in the following paragraphs does not introduce any sizeable error. Consider a volume V linear ft of air–petrol vapour mixture subject to a change in vapour pressure from p_i to p_f (p_i and p_f are obtained from Happel and Heath as fully explained on p. 313). Suppose that at some stage in this process the vapour pressure rises from p to $p + dp$, and the air–petrol vapour mixture volume changes from V to $V + dV$, then applying Boyle's Law to the air fraction,

$$V(760 - p) = (V + dV)(760 - p - dp)$$
$$\therefore\ 760\,dV - p dV = V dp + dV dp$$

The last term is of the 2nd order and can be neglected,

$$\therefore dV = \frac{V dp}{760 - p} \text{ linear ft of air at } (760 - p) \text{ mm Hg}$$

and temperature Ta, where Ta is the mean vapour space temperature during the process. This volume dV is also the volume of air–petrol vapour mixture at 760 mm Hg and temperature Ta. The petrol content of the volume increase dV,

$$= \frac{p}{760}\,dV = dG \text{ linear ft at 760 mm Hg and temperature } Ta.$$

$$\therefore dG = \frac{V}{760} \times \frac{p}{760 - p} \times dp = V\left(\frac{1}{760 - p} - \frac{1}{760}\right)dp$$

Integrating between the limits p_i and p_f,

$$G = \int_{p_i}^{p_f} dG = V\left[\log_e \frac{760 - p_i}{760 - p_f} - \frac{p_f - p_i}{760}\right]$$

As in the case of the Y terms previously, this is taken as a loss G at temperature T the bulk liquid temperature and 760 mm Hg. The total loss resulting from a series of transfers from the tank will, of course, be

$$\Sigma G = G_1 + G_2 + G_3 \ldots$$

The volume of petrol vapour lost is $\therefore A\Sigma G$ cu. ft., the N.T.P. volume lost is $\dfrac{A\Sigma G \times 492}{T}$ cu. ft., and the corresponding liquid loss

$$= \frac{A\Sigma G \times 492}{T} \times \frac{M}{D \times 359 \times 6{\cdot}23} \text{ cu. ft.}$$

Taking $\dfrac{M}{D}$ as 10·8, the percentage loss in tank capacity

$$= \frac{A\Sigma G \times 492 \times 0{\cdot}483}{T \times A \times (H - 1)}, \text{ where } H = \text{tank height},$$

$$= \frac{0{\cdot}483 \times \Sigma G}{(H - 1)} \times \frac{492}{T}$$

The $\left(\dfrac{492}{T}\right)$ correction term can be omitted for the same reasons as applied on p. 16, hence the pumping-down loss $= \dfrac{0{\cdot}483\Sigma G}{(H - 1)}$ percentage of tank capacity. This value must be subtracted from the " combined "

loss from the tank to give the percentage loss due only to thermal breathing.

Calculation of the Ratio of Effective Internal to External Temperature Ranges from the Survey Results

Suppose that in an N day test the thermal breathing loss is found to be e per cent of tank capacity. If C is the capacity of the tank in cu. ft. then the loss in cu. ft. of liquid $= \frac{Ce}{100}$. The loss in weight $=$ $0{\cdot}0623CeD$ lb, where D is the density in lb/I.G. The corresponding N.T.P. volume of petrol vapour is $\frac{0{\cdot}0623 \times 359CeD}{M}$, where M is the molecular weight of the evaporate. If p = the vapour pressure (mm Hg) of the liquid at bulk storage temperature and the saturation factor of the breathe is f ($f = 0{\cdot}8$ when the breathe is 80 per cent saturated) then the volume of breathe at N.T.P. $= \frac{0{\cdot}0623 \times 359 \times 760CeD}{Mfp}$ cu. ft. At ordinary temperature T (bulk liquid temperature as an approximation) the breathe

$$= \frac{0{\cdot}0623 \times 359 \times 760CeDT}{492NMfp} \text{ cu. ft/day}$$

Substituting the normal value of 10·8 for $\frac{M}{D}$ (see later note about long storage petrol) gives the breathe $= \frac{3{\cdot}20\,CeT}{Nfp}$ cu. ft/day. If the mean volume of the vapour space during the test is V cu. ft. and the total range of the breather valves is θ inches w.g., then if the valves had not been present an additional breathe of approximately $\frac{\theta V}{408}$ cu. ft. would have been expected, and this quantity therefore represents the breathe restrained by the valves. ∴ the total breathe including that retained in the tank by the valves

$$= \frac{\theta V}{408} + \frac{3{\cdot}20\,CeT}{Nfp} = v \text{ cu. ft/day}$$

Now reason suggests that $\frac{v}{V}$ would be equivalent to some temperature term $\frac{R}{T}$, *i.e.* the breathe per unit volume of vapour space is equal to the temperature effect in the vapour space per unit of base vapour-space temperature (bulk liquid temperature must be taken as the base vapour temperature as the latter is not known). In fact, the quantity Ri, which has been termed the effective internal temperature range, can be defined by the equation $\frac{v}{V} = \frac{Ri}{T}$, Ri being an empirical quantity having the dimensions of a temperature but no other physical significance, which takes into account temperature change, vapour pressure change, condensation, re-evaporation, etc., in the vapour space. Then $Ri = \frac{vT}{V} = \frac{\theta T}{408} + \frac{3{\cdot}2\,CeT^2}{NVpf}$

and if the external temperature range producing this effective internal temperature range is Re,

$$y = \frac{Ri}{Re} = \left(\frac{\theta T}{408} + \frac{3{\cdot}2\,CeT^2}{NVpf}\right) \Big/ Re$$

T, the mean bulk storage temperature, is obtained from the site data supplied to us, but it has been found that T varies very little from 2° F above the mean atmospheric temperature for the test period, and when using the equation in reverse to predict losses this fact is used to get the bulk liquid temperature from Meteorological Office data.

Chenicek–Whitman Determinations

The Chenicek–Whitman apparatus (Fig 9) enables a quantity of wet saturated air at 75° F, whose volume is measured in burette A and pressure determined by

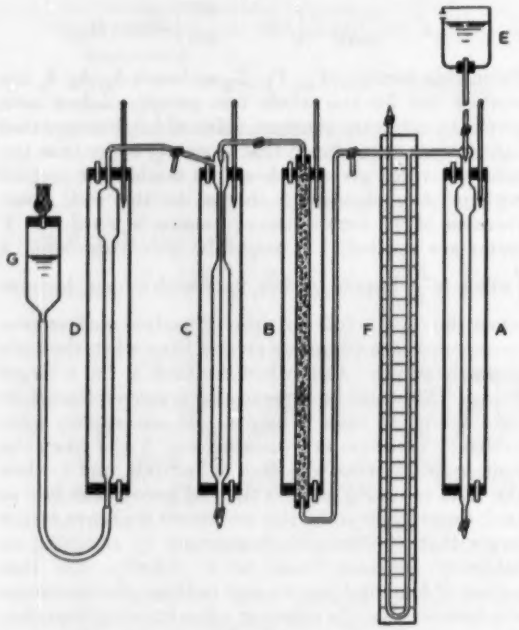

FIG 9

manometer F, to be displaced from burette A (by means of water supplied from the "head" tank E) through drying tower B and then through a capillary tube reaching to the bottom of the long vessel C holding the 100 cc of petrol under test.

The air bubbles generated by the capillary rise to the surface saturated with petrol vapour and the volume of dry air and saturated vapour so formed is collected over glycol and measured in burette D, using the levelling device G.

The upper portion of the vessel C has a narrow neck which is graduated so that the loss in liquid volume which has occurred during the bubbling can be accurately measured.

From a series of such measurements and knowing

the barometric pressure the vapour pressures of the spirit with increasing percentages distilled off by the bubbling can be found. The logarithm of the vapour pressure gives a straight line when plotted against the percentage evaporated. By such determinations performed on initial and final samples taken from the tank under test, the percentage which must be evaporated to degrade the initial sample to the state of the final sample can be obtained. This is the percentage loss which has taken place in the tank liquid from which the final sample was drawn.

The Determination of $\frac{M}{D}$ *from Chenicek–Whitman Data*

The value of $\frac{M}{D}$ for petrol under test can be obtained from the measurements, described above, as follows:

Let the total wet air volume under a pressure of h cm of water, used in the first n points of the determination (n being such that the total U per cent evaporated is just less than 2 per cent) be v cc. (The 2 per cent corresponds to a typical loss in the end sample as a result of combined standing storage and pumping-down loss.) A pressure of h cm of water $= 0{\cdot}733h$ mm Hg. In all tests h has been kept constant at 61·8 cm, and $\therefore$ the pressure due to the water column

$$= 61{\cdot}8 \times 0{\cdot}733 = 45{\cdot}3 \text{ mm Hg}$$

If v is the volume wet at 75° F and under pressure, the volume dry at 75° F and under pressure

$$= \frac{v(A + 45{\cdot}3 - 22{\cdot}4)}{(A + 45{\cdot}3)} = \frac{v(A + 22{\cdot}9)}{(A + 45{\cdot}3)}$$

where A = the barometric pressure in mm Hg, 22·4 being the vapour pressure of water at 75° F. The volume at pressure A

$$= \frac{v(A + 22{\cdot}9)}{(A + 45{\cdot}3)} \times \frac{(A + 45{\cdot}3)}{A}$$

$$= \frac{v(A + 22{\cdot}9)}{A}$$

$$= kv \text{ cc, where } k = 1 + \frac{22{\cdot}9}{A}$$

Over the range $A = 730$ to 780 mm the total variation of k is only 0·2 per cent. Taking the mean value for k of 1·030, if the total final volume of petrol + air at pressure A and 75° F from the n determinations is V_1 the volume of petrol vapour alone is $(V - 1{\cdot}030v)$ cc, and the corresponding N.T.P. volume is

$$(V - 1{\cdot}03v) \times \frac{492}{535} \times \frac{A}{760} \text{ cc}$$

$$= 0{\cdot}00121A(V - 1{\cdot}03v) \text{ cc}$$

The corresponding weight of petrol

$$= \frac{0{\cdot}00121A(V - 1{\cdot}03v)\,M}{22400} \text{ g,}$$

where M is the molecular weight of the evaporate,

$$= 0{\cdot}54 \times 10^{-7} \times MA(V - 1{\cdot}03v) \text{ g}$$

But the volume of petrol evaporated $= U$ per cent $= U$ cc $= Ud$ g, where d is the density of the evaporate in g/cc.

$$\therefore\ Ud = 0{\cdot}54 \times 10^{-7} \times MA(V - 1{\cdot}03v)$$

$$\therefore\ \frac{M}{d} = \frac{U}{0{\cdot}54 \times 10^{-7}A(V - 1{\cdot}03v)}$$

If D is the density in lb/I.G., *i.e.* $D = 10d$

$$\frac{M}{D} = \frac{1{\cdot}85 \times 10^{6}U}{A(V - 1{\cdot}03v)}$$

For normal petrol $\frac{M}{D}$ varies very little from 10·8. For long storage petrol the value varies little from the mean of 11·4.

The Basis of the Nomograms for Thermal Breathing Loss

The correlation expression

$$y = \left(\frac{\theta T}{408} + \frac{3{\cdot}2CeT^2}{0{\cdot}8NpV}\right) \Big/ Re$$

can be re-arranged as follows:

$$yRe - \frac{\theta T}{408} = \frac{4{\cdot}0CeT^2}{NpV}$$

$$\therefore\ e = \frac{NpV}{4CT^2}\left(yRe - \frac{\theta T}{408}\right)$$

$$\therefore\ e = \frac{NpV}{4CT}\left(\frac{yRe}{T} - \frac{\theta}{408}\right)$$

For any month ($\frac{1}{12}$ of a year) the loss is given by

$$\left(\frac{V}{C}\right)\left(\frac{p_m}{T_m}\right)\left(\frac{yRe_m}{T_m} - \frac{\theta}{408}\right) \times \frac{365}{4 \times 12}$$

where Re_m is the mean external temperature range for the month;

T_m the mean bulk storage temperature for the month (this being taken as 2° F above the mean external temperature for the month); and

p_m the corresponding vapour pressure at storage temperature.

This can be re-written as $\left(\frac{V}{C}\right)L_m$,

where $$L_m = 7{\cdot}61\left(\frac{p_m}{T_m}\right)\left(\frac{yRe_m}{T_m} - \frac{\theta}{408}\right)$$

and for a year the total loss will be $\left(\frac{V}{C}\right)\Sigma L_m$ over twelve months. If the mean temperature range averaged over the whole year is Ra, then

$$L_m = 7{\cdot}61\left(\frac{p_m}{T_m}\right)\left(\frac{yRe_m}{Ra} \cdot \frac{Ra}{T_m} - \frac{\theta}{408}\right)$$

Table VI shows the mean values over ten years of $\frac{Re_m}{Ra}$ and T_m for four places suitably disposed about the

English coastline, two of which, Tynemouth and Greenwich, represent extremes of temperature range. (Annual daily means are 14·8 at Greenwich and only 8·6 at Tynemouth.)

TABLE VI

	Tynemouth		Liverpool		Bristol		Greenwich	
	$\frac{Re_m}{Ra}$	T_m, ° F	$\frac{Re_m}{Ra}$	T_m, ° F	$\frac{Re_m}{Ra}$	T_m, ° F	$\frac{Re_m}{Ra}$	T_m, ° F
January	0·74	40·4	0·81	39·7	0·64	40·6	0·62	39·5
February	0·80	41·9	0·82	41·2	0·69	41·8	0·71	41·0
March	1·07	44·2	1·07	44·7	1·13	45·2	0·99	45·3
April	1·17	49·2	1·15	50·3	1·19	51·5	1·17	52·1
May	1·10	51·6	1·34	54·4	1·30	54·9	1·32	56·3
June	1·25	57·7	1·32	59·4	1·24	60·4	1·27	62·4
July	1·16	61·0	1·12	62·4	1·21	63·8	1·25	62·3
August	1·12	60·8	1·09	62·3	1·19	63·6	1·23	65·9
September	1·16	58·3	0·98	59·0	1·11	59·9	1·11	61·4
October	0·94	55·2	0·86	52·9	0·98	53·7	0·97	54·1
November	0·80	47·1	0·76	46·1	0·71	47·5	0·73	46·6
December	0·70	44·1	0·79	43·7	0·61	43·8	0·62	42·8

These values show a surprisingly regular pattern, and an examination of similar data for other places shows that this pattern seems to be general throughout the U.K. In fact, as a rough approximation it seems that for any given month on average over long periods of time $\frac{Re_m}{Ra}$ and T_m can be taken as constant from place to place. This sweeping generalization is obviously untrue at certain places for certain months of the year, but in general there is a compensating effect, *i.e.* where in one month the value of $\frac{Re_m}{Ra}$ at a given place is, say, considerably higher than the mean value for that month this error is compensated for by lower than average values in other adjacent months. In addition, the generalization is truest in the spring, summer, and early autumn when the losses are largest. In fact, it has been found by direct calculation that estimation of the loss from a tank taking the true climatic conditions at the place in question produces an almost identical result with that calculated, assuming a mean distribution of $\frac{Re_m}{Ra}$ and T_m taken over the fourteen places shown in Table III.

Proceeding, therefore, on the basis above, if T_m is a constant for a given month, then at a given Reid vapour pressure p_m must also be constant from place to place during a given month. It follows that as

$$L_m = 7{\cdot}61 \left(\frac{p_m}{T_m}\right)\left(y\,\frac{Re_m}{Ra}\,\frac{Ra}{T_m} - \frac{\theta}{408}\right)$$

then in January at all places

$$L_m = a_1\left(yRab_1 - \frac{\theta}{408}\right)$$

in February in all places

$$L_m = a_2\left(yRab_2 - \frac{\theta}{408}\right), \text{ and so on.}$$

The annual loss

$$= \left(\frac{V}{C}\right)\Sigma L_m = \frac{V}{C}\left(yRa(a_1b_1 + a_2b_2 + \ldots) - \frac{\theta}{408}(a_1 + a_2 + \ldots)\right)$$

in other words the annual loss can be treated as a function of $\frac{V}{C}$, yRa, θ, and the absolute vapour pressure of the spirit at 100° F. The nomograms shown in Figs 4, 5, 6, and 7 are the product of this treatment.

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DISCUSSION

A. H. Stephenson: In so far as evaporation loss studies in the U.K. are concerned, the paper will do much to remove the difficulty that was commented on at the Symposium of the IPA in the U.S.A. in regard to the absence of reliable data on the subject as it affected storage in that country. The tremendous amount of data in the paper will be of very great assistance to the many people in the industry who are vitally concerned with this important question of evaporation losses from storage tanks.

The authors must have experienced difficulty in producing their results other than in tabulated form, but I had hoped that they might have added a little information in one or two directions. For instance, as the tests referred to 36 tanks involving 127 separate sets of readings, it would be helpful if one could have the code numbers of the various tanks involved so that it would be possible to compare the different performances of the same tanks under different temperature conditions and sometimes under different innage conditions.

I would also like to ask the authors, in view of the importance attached to the accuracy of the Chenicek–Whitman test method to the results obtained, whether, in addition to the tests carried out in the preliminary stages of the survey which are mentioned in the paper, they were able to take advantage of any of the opportunities that arose on some of the tests where tanks were standing for long periods with no movement of the product at all, and did they take a check on the accuracy of the Chenicek–Whitman results obtained as compared with the basic dip method? I was particularly interested when studying the paper, not in those cases where the losses are greater than one might expect and which could be attributed to several reasons which the authors have detailed, but in those where the loss is much less than might have been expected.

For instance, in comparing tests 82 to 86 with tests 96 to 100, two groups of five tanks, each located in the same part of the country, are of the same size, with the same innage, operating through more or less the same temperature range, and both were subject to tests which were carried out simultaneously and continued for approximately six months.

There was, admittedly, a slight variation in the vapour

pressure of the product stocked and a slight variation in the conservation valve settings, but the interesting point is that all the tanks in the first group are shown as "tight" and all those in the second group as "leaking," and yet from the figures shown it appears that the loss from the tanks that were "leaking" was in several cases less than that from the tanks that were "tight." As the authors have stressed that tanks were only classed as leaking when there was no doubt that this was the case, I shall be interested to hear their views on these results.

In regard to the application of the results to working tanks. In the authors' references they quote two typical cases, first where tanks were pumped down in drops of several feet with three or more days between most of the drops, and secondly, where a tank was pumped down in six 5-ft drops at seven-day intervals. This is very different from the type of working tank which those on the distribution side of the industry have to deal with, as, in general, if a tank becomes a working tank it is then that drawing takes place regularly day-by-day until that tank is exhausted. It could not be otherwise, because if there is an interval of days between movements it must mean either that one has no demand for that particular product or that one has alternative tanks from which one can draw the same grade, both of which are unlikely eventualities.

On this type of working tank, which is much the most common within the industry, I am doubtful as to whether the assumption that all vapour lost is 80 per cent saturated. This question of saturation is one which will undoubtedly receive more and more attention as the study of evaporation losses continues, and recently my company investigated thoroughly the working losses at a completely new distribution depot where the tanks were completely tight and fitted with efficient breather valves of a type of which the authors would undoubtedly approve. On this test, which continued for a period of a month, and during which every movement of product was accurately recorded, it was calculated that the overall saturation figure for the vapour expelled amounted to 55 per cent. As this figure is much less than the 80 per cent used by the authors, their comments will be appreciated.

The authors in reply said:

We agree that it is interesting to compare the results of a series of tests on the same tank. Such tests can be found from Table II on the general basis that in a given area, only one tank of a stated size and stated valve range was under test, *e.g.* only one tank in the Merseyside area of size 46 × 35·25 ft and having +8 and −2½ valves was tested, and hence tests 1, 18, 31, and 121 were repetitive tests on the same tank.

Exceptions to this rule are the 9 × 30 horizontal tanks and those listed below:

Tank	Tests
A	5, 32, 58, 94, 124
B	6, 33, 61, 95, 127
C	34, 60, 93, 126
D	35, 59, 92, 125
E	25, 53, 82, 107
F	26, 54, 83, 108
G	27, 55, 84, 109
H	28, 56, 85, 110
I	29, 57, 86, 111
J	38, 63, 96, 112
K	39, 64, 97, 113
L	40, 65, 98, 114
M	41, 66, 99, 115
N	42, 67, 100, 116
O	79, 104, 118, 123
P	80, 105, 117, 122

A comparison has been made of tests 82–86 as against 96–100. We are as much mystified as Mr Stephenson as to why in this case the losses came out in favour of the tanks classified as leaking. The latter group listed above as tanks J to N often gave lower losses than expected, particularly bearing in mind that: (*a*) none of this group ever showed signs of holding any pressure or vacuum on any of the occasions when we were at this site, and (*b*) that these tanks had mid-green paintwork.

In regard to the question of the assumption of 80 per cent saturation of the breathe from a tank. This figure was based on quite a lot of work with an Orsat apparatus, and it is necessary to stress again that this figure was chosen as an overall average applicable to the tanks tested in the survey, *i.e.* a mixture of some standing tanks, some tanks working down in stages, plus a few working down irregularly. It is an overall figure and, as such, must at times be in error, and is therefore one of the sources of scatter in the results. Mr Stephenson has made reference to a test performed on some depot tanks. It was to be expected that such tanks were working rapidly and continuously, and would therefore give rise to lower saturation values and lower thermal breathing losses. Such tanks are not thought to be typical of normal installations. Our figures showed a considerable scatter—some as low as 40 per cent saturation were obtained from tests on tanks which had worked down earlier in the day on which the tests were made. The 80 per cent figure was the mean of a substantial number of test results on both working and standing tanks taken at what appeared to be a typical installation.

Fortunately, as pointed out in the paper (see p. 307), no great error will be caused when predicting losses from the survey results by using a wrong saturation factor, providing the predictions are applied to tanks working down at overall rates similar to those covered by the survey. On some installations it is customary for any given tank to remain stationary for two or three weeks, then work down to a low innage over a period of, say, a a week or ten days, and finally remain at a low innage for a matter of some days before replenishment. In these circumstances, one would still expect 80 per cent saturation to apply—lower figures during the working period being offset by higher than 80 per cent figures during the initial standing period. However, with the pumping down being a continuous process, in this case pumping out losses lower than those shown in Table IV might be expected.

Mr Stephenson inquired to what extent were the Chenicek–Whitman losses checked against dip readings on the long-standing tests. This was not done in the case of tanks J, K, L, M, and N. The Chenicek–Whitman losses were in four cases between 7 and 30 per cent less than those shown by dipping. Unfortunately, all the tanks concerned showed stains running down from some of the rivets and it was suspected that liquid loss might be occurring. In the fifth case, the dip figures showed a loss of about double the determined loss. This tank had, in addition to the stain marks, lost a lot of liquid suddenly for no obvious reason. The matter has not been pursued further because of a general feeling that the dip method applied to large riveted tanks does not constitute a satisfactory standard.

On the only occasion on which a relatively long term check (three months) in an all-welded tank has been possible, the agreement between dipping and Chenicek–Whitman was very good.

J. C. T. Wilkie: When the method of computing tank losses—as presented today—is used to compare results with those obtained by a National survey team in the U.S.A., a large discrepancy in the magnitude of loss assessment is evident. For example, consider two API tanks each 40 ft high and having a vent valve range of 1½ inch W.G. One tank of 55,000-brl capacity (100 ft dia) and the other of 10,000-brl capacity (42·5 ft dia).

In the case of the larger tank, the U.S. survey gives the loss as 2·51 per cent nominal capacity—the authors'

method of assessment, including turnover component, gives loss as 1·45 per cent nominal capacity. This is a discrepancy of over 40 per cent and represents a difference in breathe loss assessment of about 600 gal of product p.a.

In the case of the smaller 10,000-brl tank the U.S. figure for loss is 2·97 per cent tank capacity, and that derived from the authors' work is 2·12 per cent nominal capacity, giving a difference in assessment of approximately 30 per cent, which in terms of liquid loss assessment difference p.a. = 85 gal.

At first, these large discrepancies may appear to be owing to different values in tank turnover and from errors of assumed values of the factors T, V, and p used in the formula to compute the value of Ri—the measure of internal tank conditions. The turnover values, however, are roughly the same in both assessments, and I agree with the authors that although the values assumed for T, V, and p are not the real values controlling the magnitude of breathe, errors in these assumptions to obtain values for the Y ordinates of the correlation curve will be cancelled out when using the curve to assess losses.

On further investigation, the discrepancy in results appears to be related to tank form, and they may be found to be directly proportional to some function of tank diameter and inversely proportional to some function of tank height. If this is so, their cause might lie in the methods used to determine the physical magnitude of the breathe loss from the tanks selected for survey purposes.

In the case of the U.S. survey, the method for measurement of loss is not given, but the results quoted, being the average of many tests each giving fairly consistent results and conducted by eight different companies using a variety of methods, can be taken as fairly representative of average losses from various tank sizes of API construction.

The authors method of measuring breathe would appear to be based entirely on results of product sample tests using Chenicek–Whitman apparatus.

The use of this apparatus is, I agree, a fairly accurate means of measuring the loss of product light ends, which, when lost, reduce the vapour pressure of the product specimen to that of the final samples taken from the selected tank. However, the nature of evaporation of the product specimen by the Chenicek–Whitman apparatus is not representative of the evaporation of product from the accepted type of bulk storage tank.

In effect, the evaporation chamber of the apparatus (Chamber C, Fig 9) is similar to a very tall, narrow tank, and "weathering" of the product is obtained by forced agitation. With this system the lightest of the fractions from the product specimen—and only the lightest fractions—are evaporated.

The mechanism of breathe from a tank—which by comparison is large and squat—is such that the major effect producing breathe is felt in the liquid and vapour layers immediately adjacent to the tank shell and roof, particularly that part of the shell and roof directly affected by radiant solar heat, with the result that the product evaporate rises from the liquid surface up the tank shell to the roof, from where it is expelled through the tank breather valves. The bulk of the vapour space and the liquid product remains relatively unaffected by daily external temperature range, or daily rise in temperature of the tank metal. This theory is supported by the late Dr Koefold.

Evaporation of the liquid is from a large surface area without agitation of the volume, and owing to the low conductivity factor of the product, high liquid surface temperatures—particularly at points adjacent to tank shells—will be experienced, which will result in the evaporation of fractions of the product heavier than the fractions evaporated from the same product specimen in Chamber C of the Chenicek–Whitman apparatus (Fig 9).

It will therefore be evident that, although overall, the vapour pressure of the stored product is reduced by evaporation loss, because this loss is maintained for a short period daily from a small volume of the bulk product at high temperature, the magnitude of loss cannot be related directly to the drop or reduction in average vapour pressure of the total product stored.

For these reasons, although it is possible to obtain a weathering of the product in the Chenicek–Whitman apparatus equal to the average weathering of the same product in a bulk storage tank in terms of product vapour pressures, the nature of weathering renders this a quality assessment and not a measurement of quantity, and Chenicek–Whitman analysis used here will give incorrect results—the error involved will be large in the case of tanks of large diameter and low height, reducing through lesser diameters and greater heights to fair accuracy in the case of small vessels, particularly vessels similar in form to Chamber C of the apparatus.

It is possible that the Chenicek–Whitman loss figures might be related to actual tank losses by the use of a differential based on tank diameter and height.

A further point deals with the term pumping down loss. Where distribution tankage having low utilization values is concerned, pumping down losses are insignificant, as the loss experienced in this way is approximately equal to the loss that would be experienced from an undisturbed tank of average innage. Thus, a formula or system which provides estimates for evaporation losses based on a daily average cycle will automatically cover for pumping down where tank turnovers are less than 20 p.a.

Finally, past experience has indicated that although loss estimates are possible by using methods based on daily average conditions, the fractional functions are of such small dimensions that extreme accuracy in determining formula values is essential for good results. I would therefore suggest that the authors furnish nomograms and correlation curves to a much more elaborate and detailed scale, as use of these curves on the scales at present provided gives only very approximate results.

The authors in reply said:

Mr Wilkie has compared our findings with U.S. data given in the U.S. Evaporation Loss Symposium. In the absence of more comparable data this seems a reasonable step to take. The results of such a comparison indicate discrepancies of the order quoted, and from these discrepancies Mr Wilkie deduces that the authors' results are in error, and the reason for this error is ascribed to the use of the Chenicek–Whitman method.

It is interesting, first, to look at the standard of comparison. This consists of eight different company assessments of the loss from a range of tank sizes, at a given innage and Reid vapour pressure, these assessments being based on workable charts and tables obtained by piecing together all available data. For a 10,000-brl tank the annual loss assessments vary from 225 to 438 brl. For a 55,000-brl tank the assessments vary from 1090 to 1815 brl. There is here clearly a considerable range of opinion as to the size of the loss to be expected.

Secondly, these assessments are U.S. assessments, and are presumably therefore based on determinations under U.S. climatic conditions, which are considerably different from British, these differences being sufficiently great to lead one to expect some divergence in the results even after due allowance has been made for the difference in the temperature ranges operative.

Thirdly, the results obtained were interpreted in a most conservative manner so that in using the correlation curve as it is now drawn they will give safe minimum estimates of the loss. (This point is covered in more detail in our reply to Mr A. C. McGechan.)

With respect to the Chenicek–Whitman method, the pilot tank experiments were performed on a tank whose dimensions bore no relationship whatsoever to the evaporation column of the apparatus, but the agreement obtained between this and direct dipping in circumstances where more than ordinary confidence could be placed in the dip results, was excellent.* The method has been widely used in the U.S.A., and it is suspected that many of the U.S. Symposium background tests were made by this method.

R. L. Sarjeant: I agree with the authors in that breathing losses constitute by far the greater proportion of the overall losses. They are directly owing to temperature changes in the vapour space, and it seems unwise to calculate these temperature changes from overall losses found by experiment (such losses being subject to experimental and human error), when such temperature changes are so easily susceptible to direct and accurate measurement by means of a recording instrument placed in the vapour space. This gives very little trouble, and does not entail much work—merely changing a sheet of paper from time to time, and one would then get the accurate temperature changes in the vapour space instead of calculating these indirectly. The evaporation losses, as the authors say, include other losses besides the breathing losses, and therefore the temperatures calculated from these total evaporation losses by no means represent the temperature changes in the vapour space itself. If one refers to Table II, for example, for tank No. 19 factor Y is 10·2 and the external temperature range is 12·7° F, this giving an apparent temperature variation in the vapour space of 129° F by multiplying the two together. In other instances, for example tank No. 43, the figure works out to an internal temperature range of 170° F, tank No. 47 works out at 213° F, and for tank No. 115 the apparent variation in the vapour space temperature is no less than 280° F. It would have been very much more to the point if the actual temperatures had been taken. When my company was carrying out similar experiments it was found on several occasions that the losses were sometimes more and sometimes less than had been anticipated from the record of the temperature variations in the vapour space, and knowing that these temperatures were accurately taken, one was able to investigate what caused the difference. This paper seems rather to slur over the temperature change and group it all in as a lump sum to account for the total evaporation losses, including run-down losses, etc.

There is one other point which is relevant. Factor K is calculated from the ratio of the exposed shell area of the tank to the mean vapour space volume during the test. This is merely a suggestion for the authors' consideration—would it not have been better to take the ratio of the exposed shell area of the tank above the liquid level and relate this to the changes of temperature in the vapour space? The temperature changes are the cause of the evaporation loss, and the temperature of the shell above the liquid level is the governing factor in the temperature changes. That portion of the shell which is below the liquid level has very little effect on the temperature in the vapour space. It appears possible, if the reduced area were taken instead of the total exposed shell area, one might get less scatter in Fig 2. The scatter may in part be owing to taking too large an area of the shell.

Finally, there appears to be an error in Table V. In the first part, the losses consistently increase with the reduction of innage, whereas in the second part with 95 per cent innage the percentage loss is 0·95, whereas with 5 per cent innage, which represents an enormous vapour space, the percentage loss is only 0·05. Have these figures been transposed? Perhaps they can be explained.

The authors in reply said:

In regard to the suggestion that we have taken the temperature change as accounting for the total evaporation losses, including run-down losses. We would emphasize, most strongly, that we have not, in fact, done this. The various effects (of which thermal breathing is only one) causing loss of petrol are mentioned on pp. 297 and 300, and are dealt with quantitatively in the Appendix, which gives the method of determining thermal breathing loss alone and of determining an effective internal temperature range which accounts only for this thermal breathing loss. The following brief summary may help to clarify the matter.

At each stage in working down a tank, petrol is lost from the liquid into the increased vapour space above the liquid. The change in the final petrol sample caused by this transfer of petrol from liquid to vapour phase is calculated, and the Chenicek–Whitman result on the final sample is corrected for this effect. The corrected Chenicek–Whitman result now represents the combined effect of pumping-down breathe and thermal breathe. This corrected result requires interpretation, since pumping-down breathe and thermal breathe have occurred at each stage in the pumping-down process, with a different level of petrol at each stage, whereas the final sample has been taken from the petrol at its final level at the end of the pumping-down process. The method of arriving at the "combined loss" (pumping-down breathe + thermal breathe) in percentage of tank capacity is given on pp. 313–15 of the Appendix. From this combined loss, the pumping-down breathe is then subtracted, the result giving the loss caused by thermal breathing only. The Appendix, p. 316, gives the method of determining an internal temperature range which would account for this thermal breathing loss solely on a basis of temperature change in the vapour space. It is not suggested that this is an actual temperature change, since factors other than a straightforward temperature change in the vapour space determine thermal breathing, *e.g.* increase in petrol vapour pressure and re-evaporation of petrol previously condensed—that is why the temperature range arrived at in this way is termed an "effective" internal temperature range. In Fig 2, the ratio of this effective internal range to the external range is correlated with the ratio of total tank shell area to vapour space volume.

The above explanation gives one reason why we did not make direct measurements of temperature changes in the vapour space. Something was required to which we could relate the whole thermal breathe. Straightforward temperature measurements would have provided only part of the answer. A further reason was the difficulty of measuring vapour space temperatures on working tanks, where the vapour space volume varies over a wide range.

With regard to the factor k, this was arrived at after a number of attempts to find a ratio which would give a correlation with y. We have taken the total exposed shell area rather than the exposed shell area above the liquid petrol level since it gave a better correlation. The reason for this is as follows. Thermal breathe results from thermal expansion of the vapour space volume, and from increase in petrol vapour pressure. The shell area below the liquid level contributes towards vapour pressure change by heating the petrol layer around the inside of the shell, this heated petrol rising and spreading across the surface of the petrol. It therefore seems reasonable that the shell area below the liquid level, in

* The size of the diagrams shown is governed by the make-up of the paper, but we undertake to prepare some larger diagrams with suitable scales, and will be pleased to send copies to anyone who wants them and who cares to get in touch with us.

addition to the area above it, should be taken into account in the correlation. It is probable that the true factor k is not the simple one we have taken—it may be some complicated function of the two portions of the shell area—but in view of the limited information available on the processes involved, it is considered that the factor k which we have taken is a reasonable approximation, since it enables a workable correlation to be obtained.

In regard to Table V, a low loss at low innage is not as unreasonable, in certain circumstances, as would appear at first sight. The influence of vapour space volume on thermal breathe involves two opposing effects. As the volume increases, the breathe tends to increase because of the increased volume undergoing thermal expansion. On the other hand, the breathe tends to decrease, since the effective internal temperature range decreases as the volume increases. The actual breathe will depend on the resultant of these two opposing effects. If the former effect is the greater, the breathe will increase with increasing volume, while if the latter effect is the greater, the breathe will decrease. Now consider tanks having negligible valve range. From Table V, at 95 per cent innage the thermal breathe is very much less than at 5 per cent innage. This suggests that for these tanks, the effect of the increased volume is greater than the effect of the decreased effective internal temperature range. Now consider tanks having valves with a high range. From Table V, for a valve range of 22·5 inches w.g., the loss at 95 per cent innage is very much greater than the loss at 5 per cent innage—the opposite of what occurs with tanks having negligible valve range. We suggest that the explanation is as follows. At high innage the effective internal temperature range is very high and the temperature equivalent of the valve takes care of only a small part of this—hence the loss is still high. On the other hand, at low innage, the effective internal temperature range is comparatively small, and if the valve range is sufficiently high, the temperature equivalent of this high valve range is sufficient to take care of this low internal temperature range, either completely or nearly completely. The loss in these circumstances will be zero or very small.

A. C. McGechan: Mention was made by the authors of the information on losses in the U.S.A., and of the attempts which have been made to adapt this information when predicting losses in the U.K. In the absence of any comparable amount of information from U.K. tankage, this was not an unreasonable procedure. Two well-established sets of U.S. data would give losses 40 to 100 per cent greater than the losses given in Table V, the difference being greater for large tanks than for small ones. This is not entirely explained by the difference in mean daily temperature range, which I have assumed is 12·2° F in the U.K. and 17·6° F in the U.S.A. While this is an approximate comparison, it would be interesting to find a reason for the difference. Part of the explanation may be the account taken by the authors of pumping down loss.

It is noted from Table II that the majority of tanks on which tests were made had a high innage, and that in a number of cases no movement took place. It is, of course, understood why such tanks were most suitable for the purpose of taking samples. The average innage over a large number of working tanks would probably be about 60 per cent, or with reference to Fig 2, K would be about 0·2. If more points could have been plotted in this region, which is the one in which one is most interested, might the curve have been slightly different? Most of the plotted points for K.0·2 or less are above the curve. Also, when K is zero, should Y not be one? If the tank shell area becomes zero, or alternatively, the vapour space volume becomes infinite, does not the tank cease to exist, and therefore the "internal temperature range" is equal to the external temperature range. To what extent would the slight loss in volatility in the longer tests on standing tanks reduce the rate of loss compared with the rate of loss from a working tank?

The data for predicting losses may give a result which is a little conservative, and when considering the economics of evaporation prevention equipment, if there is any error, it would be on the right side. Comparison, however, of Figs 2 and 3 shows how many tanks fall short of achieving the desirable minimum of loss, and again emphasizes the importance of proper operation and maintenance.

The authors in reply said:

Mr McGechan has rightly pointed out that the most important part of the correlation curve is the lower region (say from k values of 0·4 downwards), and he would have liked to have seen more data in this region. We agree with him entirely in this, but unfortunately we could not choose or control the experimental conditions. One experimental condition which we had to stipulate was a minimum test period of about six weeks, and this condition proved to be difficult for the oil companies to meet, so that not only were we very restricted in our choice of tanks, but in addition a quite substantial number of tests had to be abandoned after the initial sample had been taken. (This was, of course, unfortunate but not unexpected.)

Now the points in this lower region of the curve are badly scattered, and the problem of laying a correlation line through these points is therefore not an easy matter. We have been guided in this respect by two general considerations. First, it is in this region that unidentified roof leaks are likely to cause the most serious error. Secondly, we wished any estimations of the loss to be of a conservative nature so that in assessing the savings which could be made by, say, higher pressure tanks or variable volume devices, these in turn would be absolutely safe minimum estimated savings.

Therefore in drawing this part of the correlation line we have ignored all abnormally high y values altogether and run a very conservative line through the remaining points.

This line therefore definitely tends to give minimum results.

Now this may not be what is desired, *i.e.* others may be more interested in assessing "probable" rather than safe minimum losses, and in this case a straight line drawn from the point $k = 0$, $y = 1$ to meet the existing correlation line tangentially at $k = 0·4$, is more likely to give the desired result.

Table V recalculated on this basis, but otherwise as previously, is shown below:

Innage tank size:	Valve range neg.			Valve range 5 inches w.g.		
	95%	60%	5%	95%	60%	5%
30 × 30	1·22	1·74	2·29	1·15	1·51	1·81
60 × 30	0·93	1·29	1·79	0·85	1·05	1·26
80 × 30	0·85	1·16	1·64	0·76	0·92	1·14
120 × 35	0·77	1·12	1·51	0·59	0·74	1·00
	Valve range 10½ inches w.g.			Valve range 22½ inches w.g.		
	95%	60%	5%	95%	60%	5%
30 × 30	1·09	1·28	0·99	0·95	0·73	0·13
60 × 30	0·78	0·77	0·71	0·59	0·24	Nil
80 × 30	0·66	0·62	0·57	—	—	—
120 × 35	0·48	0·50	0·41	—	—	—

These figures are probable losses rather than safe minimum loss assessments and, as such, may be more in keeping with U.S. findings.

In reply to other matters, it is not considered that one can reason out any theoretical limit which y should approach as k tends to nothing. We do not expect the variation in vapour pressure during the test period to have much effect, as the results have been plotted on the basis of the average vapour pressure operative during the whole of the test period. When predicting losses from the results the same procedure should be followed.

A. G. Grant: Are we not in danger of repeating the history of the past thirty years and of being too preoccupied by analytical thinking and theory which, as brought out in the API symposium, has given us very little in the way of practical results? It should be emphasized that this paper first and foremost reports investigations to find what is the actual loss in tanks all over the U.K. under a variety of conditions, including the imperfections in the tanks themselves and the people who operate them.

Secondly, there has been a doubt expressed as to the method used for determining losses. Chenicek–Whitman seems to be universally accepted in the U.S.A. The authors, not wishing to rely on that acceptance, carried out a check as between the measured losses in a tank and those determined by the Chenicek–Whitman method, and they found good agreement. Unless therefore some new evidence is produced, one would think that the method used was sound and that the results can be accepted quantitatively. When one comes to their interpretation and correlation there is perhaps some room for argument, but it is necessary to accept for the first time in the U.K. that this quantitative work has been well done. A qualified research worker has himself taken all the samples, brought them back to the headquarters of the laboratory, and done the Chenicek–Whitman work or overseen it so that there has at no point been the possibility of a slip in the sampling, handling, and laboratory sequence.

L. Holliday: It is interesting to note that the vapour pressures on the samples taken from various parts of the liquid were substantially constant. This bears out the assumption that there is no variation in the fluid composition. However, since evaporation actually takes place from the surface itself, it would be of the greatest interest to know what is the vapour pressure of the surface film, and it is presumed that the top sample does not, in actual fact, represent the surface film, but represents approximately the first foot of the liquid. In that case, are any figures available for the vapour pressure of the surface film itself?

Have the authors any experience of the flexible membrane type of device which can be installed in cone roof tanks? It is reported to eliminate vapour losses completely. I think it is called a "Vulcaloch" membrane.

In regard to re-evaporation when one is pumping down a tank, the percentage of hydrocarbon vapour in the vapour space above the liquid with which one is dealing is about 30 per cent. When one pumps down a tank from, for example, 2-ft ullage to 20-ft ullage, if that were done instantaneously, the concentration would drop to approximately 2 or 3 per cent, which would be within the explosive range. However, at normal pumping rates re-evaporation takes place during the pumping operation, with the result that the vapour concentration will be higher at the bottom of the tank than at the top. Have the authors any data on the rate of re-attainment of equilibrium?

The authors in reply said:

We are sorry that we have no information on the vapour pressure of surface films or on flexible membrane devices where the membrane floats on the liquid.

With respect to the re-attainment of vapour equilibrium following a large pumping down operation the average vapour pressure changes occurring can be obtained from the Happel and Heath curve reproduced in the Appendix to the paper. We have twice substantially verified this curve. With regard to vapour pressure differences between the top and bottom of the vapour space in a tank, our experience has been in general as follows:

In the early morning there is often surprisingly little difference between the composition of the air–petrol-vapour mixture at various levels in the tank vapour space, even when the whole vapour space is substantially unsaturated. During the daytime, however, the vapour pressure rises at the lower levels, the extent of the rise increasing as the liquid level is approached, whereas higher up in the vapour space only slight vapour pressure changes occur.

R. J. Venis: How would the authors expect the figures to apply in the case of a tank feeding a process plant, where the tank is filled and then emptied at a steady rate? Would one expect the losses to be higher or lower than the figures quoted in the paper?

The authors in reply said:

We would expect the losses from process feed tanks to be much lower than the figures quoted here, in fact, it is doubtful whether either our thermal breathing loss or pumping down loss figures could be safely applied here, as the conditions of tank working are so very different.

G. M. Minnema: I do not know whether the authors wish to continue this tremendous investigation, but several people have expressed doubts as to the accuracy and reliability of the vapour pressure determination. I myself am not familiar with that determination, but there is another possibility for checking the accuracy of these vapour pressure determinations, and that is by way of Podbielniak analyses before and after a long period of standing. In that method one determines C_2, C_3, C_4, C_5, and C_6 plus hydrocarbons. I would not recommend it as a routine method for everything, that would be too much work, but as a method of check analysis, it might be helpful in this case. From experience, I know that it works.

The authors in reply said:

Thank you for the suggestion. We have heard of this method, and it is useful to have confirmation that the method is practicable and accurate.

E. J. Sturgess: On reading this interesting paper, I came to the conclusion that the object of the authors was to try to present an idea of the yardstick one could use in calculating the evaporation losses which could be expected from thermal breathing.

I do not feel that the assessment of losses as a percentage of tank capacity is the best way of arriving at the information required. A more usual and perhaps a better method would be to give the losses which could be expected per square foot of surface area of one's tank, although the most usual yardstick which managements use is the percentage of loss on the throughput of the tank. If the authors propose to extend their investigations they should consider whether they could relate the losses to one or other of these factors which are better known to, and more usual in, the oil industry.

The authors in reply said:

While fully appreciating Mr Sturgess' point, *i.e.* the desirability of having some simple rapid means of making a rough check on losses, our aim was something quite different from this. Any consideration of the economics of the various forms of vapour saving devices necessitates a knowledge of the losses which would occur in the absence of such devices. Our work was undertaken to obtain information which would be of assistance in these

economic considerations, but which might not, necessarily, be suitable for rapid routine checking. We were therefore not concerned with the fact that the method finally arrived at for predicting losses is perhaps somewhat complicated. In addition, we did not give much consideration to alternative methods of returning results, since it appeared that expressing loss as percentage of tank capacity would be as convenient as any other method for the purpose we had in mind.

With regard to the suggestion that the loss could be expressed in some very simple way such as "per sq. ft. of surface area," we do not think that this is possible in view of the number of factors involved. Innage, valve range, petrol vapour pressure, etc., all have an important bearing, and anything really simple is out of the question as far as reliable prediction of losses is concerned. A partial solution might be to prepare a number of charts for different tanks under different conditions so that losses could be read directly from the appropriate chart, *i.e.* instead of calculating for particular conditions each time a result is required, all calculation work would be done beforehand and incorporated in the charts. However, it is appreciated that this is not what Mr Sturgess has in mind.

R. L. Sarjeant: In illustration of Mr Sturgess' comment regarding the method of expressing evaporation losses, suppose one has two tanks of exactly the same diameter but one is three times the height of the other, and both are filled to within 1 ft of the top of the tank shell, so that the volume of the vapour space in each is precisely equal and from the point of view of breathing, one would therefore expect the losses from both tanks to be the same, assuming the same external temperature range. If this loss is expressed as a percentage of the tank capacity, the figure for the higher tank would be only one-third of that of the shallow tank, whereas if the loss is expressed as so many gal/sq. ft. of surface area of the gasoline in the tank one obtains a better comparison, the loss being the same in each case.

The authors in reply said:

Although, at first, it might appear that expressing loss as percentage of tank capacity would give a loss varying directly as the tank height, a more careful consideration of the calculations involved will show that this is not so, and that there is nothing wrong, in principle, with our method of expressing results. The following notes may help to clarify the matter.

The thermal breathing loss, expressed as percentage of tank capacity, is given by $L(V/C)$ (see p. 310 and the Appendix), where V is the vapour space volume, C is the tank capacity, and L is an evaporation loss factor dependent on the vapour pressure of the petrol, the valve range, and the effective internal temperature range.

$\therefore$ actual loss, expressed in volume units

$$= (C/100) \times L(V/C) = (LV/100)$$

If L were the same for two tanks of different heights but of the same diameter, with the same vapour space volume in each, the actual loss for each tank would be the same—the loss does not depend directly on tank capacity, since in the above expression for actual loss the capacity terms cancel. Tank capacity does, however, have an indirect effect, since it affects k, the ratio of tank surface to vapour space volume. It therefore influences the effective internal temperature range (see correlation curve) and hence affects L.

Consider a 60 ft dia $\times$ 20 ft, 1 in 5 cone roof tank, fitted with +4 −1 inches w.g. valves, storing petrol whose absolute vapour pressure at 100° F is 10 p.s.i., at 100 per cent. Annual mean daily temperature range Ra = 13·5° F.

$k = [1{\cdot}02 + (4H/Do)]/[(Do/30) + H - I\,(H - 1)] =$ 0·78 in this case.

From the correlation curve, the value of y corresponding to this value of k is 7·1

$$\therefore\ yRa = 7{\cdot}1 \times 13{\cdot}5 = 96$$

The total range of the breather valves is 5 inches w.g. For valve range = 5, yRa = 96 and vapour pressure (100° F) = 10 p.s.i., nomogram 7 gives L = 7.

For 100 per cent innage, from nomogram 4, $V/C = 0{\cdot}16$.

$\therefore$ Thermal breathing loss = $7 \times 0{\cdot}16 = 1{\cdot}12$ per cent of tank capacity.

Now consider a tank of twice the height, *i.e.* 60 ft dia $\times$ 40 ft, all other factors remaining the same.

k = 1·23 in this case.

From the correlation curve, the value of y corresponding to this value of k is 9·4.

$\therefore\ yRa = 9{\cdot}4 \times 13{\cdot}5 = 127$

For valve range = 5, yRa = 127 and vapour pressure = 10 p.s.i., nomogram 7 gives L = 9·4.

For 100 per cent innage, nomogram 4 gives $V/C = 0{\cdot}08$

$\therefore$ Thermal breathing loss = $9{\cdot}4 \times 0{\cdot}08 = 0{\cdot}75$ per cent of tank capacity.

In order to assess the above percentage losses as relative actual losses it will be sufficient in each case to multiply the percentage loss by the tank capacity expressed as a height of petrol. 100 per cent innage corresponds to a petrol level 1 ft below the eaves.

$$\therefore \frac{\text{Actual loss from 40 ft tank}}{\text{Actual loss from 20 ft tank}} = \frac{0{\cdot}75 \times 39}{1{\cdot}12 \times 19} = \frac{29{\cdot}2}{21{\cdot}3} = 1{\cdot}37$$

Thus the survey predicts that the 40 ft tank would lose 37 per cent more than the 20 ft tank. This extra loss is due to the extra tank surface exposed to heat absorption, and has nothing to do with the fact that the survey gives losses expressed as a percentage of tank capacity.

E. J. Sturgess: The point I was really making was that what those in the oil industry look for is something fairly simple on this subject. If one can give a figure of evaporation loss per square foot of surface area for various types of tanks it makes a very useful and simple yardstick for checking losses at installations and depots.

The authors' results with their formula may give the same answer, but it means a rather complicated individual calculation for each tank size, which is not the kind of calculation installation managers and depot superintendents would be inclined to carry out.

W. R. Davis: May I make the alternative suggestion that the results could be expressed as a percentage of the free space volume? If one could obtain the average ullage of the tank over a period of a month, one could then correct one's results to an average monthly figure.

The authors in reply said:

As mentioned in our reply to Mr Sturgess, so many factors have a bearing on evaporation loss that it is not possible to express results in terms of any one factor. Therefore, results cannot be returned as a percentage of free space volume.

B. C. Ferguson: There are several points which I should like to raise with the authors. The first concerns the rather difficult question of sampling. The original data upon which Chenicek and Whitman based their adoption of a single middle sample for the test were not by any means conclusive, and the very limited tests carried out by the authors of the present paper cannot be considered as offering any real corroborative evidence of the adequacy of such a single sample.

Some years ago, my company carried out a large number of tests with the Chenicek–Whitman apparatus, both in the U.K. and abroad, and it was found that a sample drawn from the middle of the gasoline depth, was in many cases not representative of the tank's contents. The regular vapour pressure gradient indicated by the authors was certainly not usually ascertained—in fact, the

level at which the highest vapour pressure was found varied from test to test. In order to obtain reliable loss figures, therefore, it was necessary to average the results of determinations on three samples, *i.e.* the usual upper, middle, and lower ones.

As one might expect, the difference in vapour pressure between samples drawn from different levels appeared to depend on the thermal conditions in the tank during the period immediately preceding the sampling. After periods of cool, cloudy weather when convection currents in the tank were at a minimum, the lowest vapour pressures were found at the upper layers, whilst after periods of hot sun the lowest vapour pressures were found irregularly dispersed through the tank. A simple laboratory test confirmed that diffusion by changes of density produced by evaporation was so slow that its effects could be neglected.

With regard to Table I, the difference between top or bottom samples and the middle samples represents a loss of about 0·16 per cent, which is appreciable and probably represents at least five days' breathing loss on the whole tank contents. Bearing in mind that after another period the gradient might be quite different, the possible error introduced would be appreciable.

Table I also indicates clearly that with working tanks having a similar vapour pressure gradient, serious underestimation of breathing loss may result from withdrawals taking place from layers at the bottom of the tank which have undergone evaporation, before such layers have a chance of being mixed into the main body of the gasoline by further thermal changes.

The second point I should like to raise concerns the dimensions of the formula by Ri which do not appear to be those of temperature.

Thirdly, in the example in connexion with the "pumping down loss" and "filling loss" following Table IV, the authors have apparently taken into consideration only that part of the loss occurring during the "pumping down" of a tank, caused by the rise in vapour pressure, and have ignored the loss through the saturation of the induced air. Further, the effect of the gasoline temperature has been ignored. The total "displacement" loss for the example given, assuming an average storage temperature of, say, 60° F, would be not less than 0·18–0·20 per cent per turnover or for eight turnovers about 1·6 per cent of tank capacity. On the other hand, the authors have included a "pumping in loss." Is this the loss caused by rise in the vapour pressure owing to increased evaporation through turbulence effects? If so, the figures quoted appear very high, particularly as turbulence would become progressively less as the tank was filled.

The authors in reply said:

First, on the question of sampling there appears to be some disagreement. The Chenicek–Whitman sampling tests were followed by three of our own, and these appeared very conclusive, so that we did not feel justified in pursuing the matter any further, particularly as each such test involves the analysis of a large number of samples. We would like to get together on this matter with Mr Ferguson, and it may well be that the discrepancy in our findings is connected with the history of the tanks prior to sampling.

Mr Ferguson rightly points out that the figures in Table I show a bottom sample considerably deficient in lighter fractions compared with most of the spirit in the tank; therefore when working down a tank there would be a tendency to constantly draw off a disproportionate amount of the spirit which had undergone most evaporation. This may be true up to a point, but we would point out that figures in Table I were obtained from a tank which had been stationary for several weeks prior to sampling. In the other sampling tests where tanks had remained stationary for shorter times no such marked effect is present. Mr Ferguson's own tests showed random variation, and not a consistent deficiency in the bottom sample, so that the balance of the evidence here seems to indicate that this effect is one which can occur occasionally when a tank stands for a long time, but would probably not be present in a working tank. The effect, if present, would be to cause an under-assessment of the loss.

Mr Ferguson, dealing with the figures in Table I, finds a difference between top or bottom and middle samples equivalent to a loss of 0·16 per cent, which is appreciable. However, if the middle sample is compared with the true mean of the contents of the tank obtained by plotting the vapour pressure against depth it will be found that the middle sample differs from the true mean vapour pressure by less than an amount equivalent to a loss of 0·02 per cent, and surely this is the relevant point.

Turning now to the correlation formula, the terms Ri and Rs are both daily temperature ranges, and both therefore have the "dimensions" (temperature) × (time)$^{-1}$, the left-hand side of the expression is therefore non-dimensional. On the other side the two groups in the brackets can be treated as follows:

θ is a daily pressure range, while the constant 408 is a pressure, hence the group $\theta T/408$ also has the dimensions of (temperature) × (time)$^{-1}$. In the second group, C and V cancel, e and f have no dimensions, so one is left with $3{\cdot}2T/Np^2$. N, being the duration of test, has the dimensions of time, and from the derivation of the equation it can be seen by similar reasoning that the constant 3·2 has the "dimensions" of (pressure) × (temperature)$^{-1}$, thus the group $3{\cdot}2T/Np$ also emerges with the dimensions of (temperature) × (time)$^{-1}$, and thus both sides are non-dimensional.

Finally, on the matter of pumping down and filling loss we have been misunderstood here. Our pumping out loss is the petrol which leaves the tank during the gradual working down of the tank as a direct result of the pressure rise caused by evaporation into the vapour space. It does not include petrol which has left the liquid for the vapour space and has remained there. This latter fraction becomes a displacement loss from the tank only when fresh petrol is pumped into the tank, although as far as the liquid stock is concerned it has, we agree, already been lost. This latter loss we have referred to as a filling loss.

B. C. Ferguson: I confirm that my company used the water displacement method of sampling, but took even more precautions than the authors. For example, before corking the sample bottles it is necessary to remove a small quantity of liquid to allow for thermal expansion and, to ensure that the same air space was left, a fixed volume was removed with a pipette each time. The precaution of transporting and storing the sample bottles upside down was also taken, so that liquid and not vapour would be lost from any bottles developing leaking closures. All bottles were also transferred to a refrigerator immediately on receipt by the laboratory.

D. A. Peters: Another point not mentioned in the paper concerns the colours of all the tanks used. Were these the so-called silver colour, apart from the few that were coloured green? Colour has an important effect on the heat absorption characteristics of a tank. A white painted tank, for example, is reputed to give about 10 per cent less loss than a silver painted one.

The authors in reply said:

With the exception of one group of five tanks painted green, the rest of the tanks under test had aluminium paintwork in normal condition, *i.e.* they were neither brand new nor in a very dilapidated state.

The meeting then closed with a unanimous vote of thanks to Messrs E. H. Walker, R. M. Eltringham, and A. Puttick.

REVISED METHOD, IP 71T, FOR THE DETERMINATION OF KINEMATIC VISCOSITY IN CGS UNITS*

THE IP viscosity panel in conjunction with the British Standards Institution and the American Society for Testing Materials has revised Method IP 71, Viscosity (kinematic in CGS units), which describes test procedures for measuring, by means of glass capillary-type viscometers, the kinematic viscosity of oils that flow in a Newtonian manner under the conditions of the test.

The revised method is now applicable both to transparent and opaque oils and may be used over a wide range of temperature. With the listed IP thermometers, the temperature range is from −65° to +212° F.

A large number of generally acceptable and accurate test viscometers is available, and some of these together with their specific requirements are described in a separate appendix to the method. Miniature viscometers for use when the test sample is available only in limited quantities and reverse-flow viscometers for opaque oils have been included.

The basis of all viscosity measurements is the viscosity of freshly distilled water at 20·00° C, which has, since 1 July 1953, been accepted as 0·01002 Poise (1·0038 cS). All test viscometers for use with oils are calibrated by means of secondary calibrating liquids of accurately known viscosity, referred to the viscosity of the primary standard (freshly distilled water at 20·00° C). These secondary calibrating liquids are usually stable oils selected to cover the desired viscosity range.

Master (or calibrating viscometers) are described, together with the procedure for their use, in a separate appendix. These viscometers are required for basic calibration purposes, and are used for determining the viscosity of secondary calibrating liquids. They are so designed that the effect due to surface tension differences and the quantity B/t is negligibly small (less than 0·1 per cent) in relation to the term Ct of equation (1).

$$\nu = Ct - B/t \quad . \quad . \quad . \quad . \quad (1)$$

where ν is the kinematic viscosity; C, the constant of the viscometer; B, the coefficient of kinetic energy of efflux, and t, the flow time in seconds.

To provide a nearly equal overlap between test viscometers with adjacent constants it was found convenient to describe viscometer series having C constants (cS sec^{-1}) of 1 and 3 times powers of 10, namely, 0·003, 0·01, 0·03, 0·1, 0·3, . . . 3, 10, 30.

The IP viscosity panel has given considerable attention to the problem caused by the difficulty of experimentally determining the coefficient of kinetic energy B. Complaints of the cost in time of measurement and the unreliability of experimentally determined values of B when different kinds of oils are involved have led the panel to consider means, where possible, of avoiding the use of B. Approximate values of B for several viscometers, obtained by calculation from their dimensions together with the method of calculation, have been given in an appendix.

Values of minimum flow times and the method of calculating these minima, when the term B/t of equation (1) is not greater than 0·1 per cent of the flow time, are also given.

Some approximate minimum flow times, when the shortened equation (2) derived from equation (1), namely:

$$\nu = Ct \quad . \quad . \quad . \quad . \quad . \quad (2)$$

may be used as follows:

Viscometer C constant (cS sec^{-1})	Minimum flow time (sec)
0·1 and over	200
Below 0·1–0·03	300
0·03–0·01	500
0·01–0·003	900

Minimum flow times vary with the design of the viscometer, and accurate values may be calculated by the method given.

It can be shown from Poiseuille's law and the Hagenbach–Couette correction for kinetic energy of efflux that

$$\text{Constant } C = \frac{\pi d^4 hg}{128Lv} \text{ and } B = \frac{mv}{8\pi L}$$

where d is the capillary diameter; h, the mean head of liquid; L, the corrected length of capillary (which may be taken as the length plus three times the diameter); v, the volume of liquid; m, the "constant," to which small positive values up to 1·5 have been assigned.

If m is taken as unity and the viscosity unit is the cP or cS then:

$$B = 3{\cdot}98\, v/L \quad . \quad . \quad . \quad . \quad (3)$$

from which it is possible to calculate values of B.

To calculate minimum flow times the following equation may be used:

$$t_{min} = 63\sqrt{\frac{v}{LC}} \quad . \quad . \quad . \quad (4)$$

The percentage error, x, due to omitting the kinetic energy correction is given by

$$x = 100\, B/Ct^2 = \frac{398v}{Ct^2L} \text{ (since } B = 3{\cdot}98\, v/L)$$

* MS received 6 June 1955.

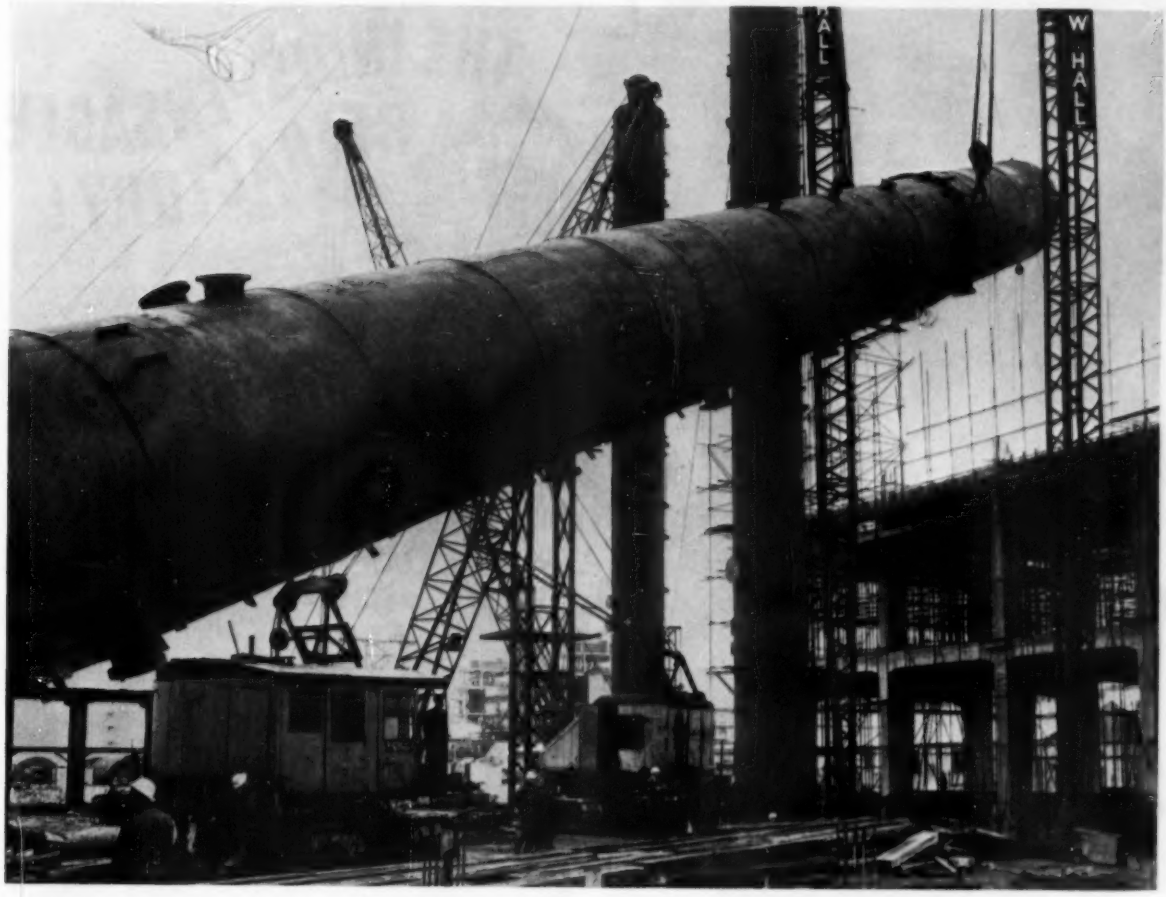
where the symbols have the same meaning as before, therefore

$$t = 20\sqrt{\frac{v}{xLC}}$$

from which equation (4) is derived when $x = 0{\cdot}1$ per cent.

The accuracy required in timing is obtainable by means of a jewelled lever stop watch or electrical timing device graduated in divisions of 0·2 sec or less and accurate to within 0·07 per cent when tested over a period of not less than 15 minutes.

The methods of checking the thermometer, selecting, cleaning, and calibrating a viscometer, and of expressing the results of a determination have been rewritten in the light of recent experience and practice.



THE

MATTHEW HALL

GROUP OF COMPANIES

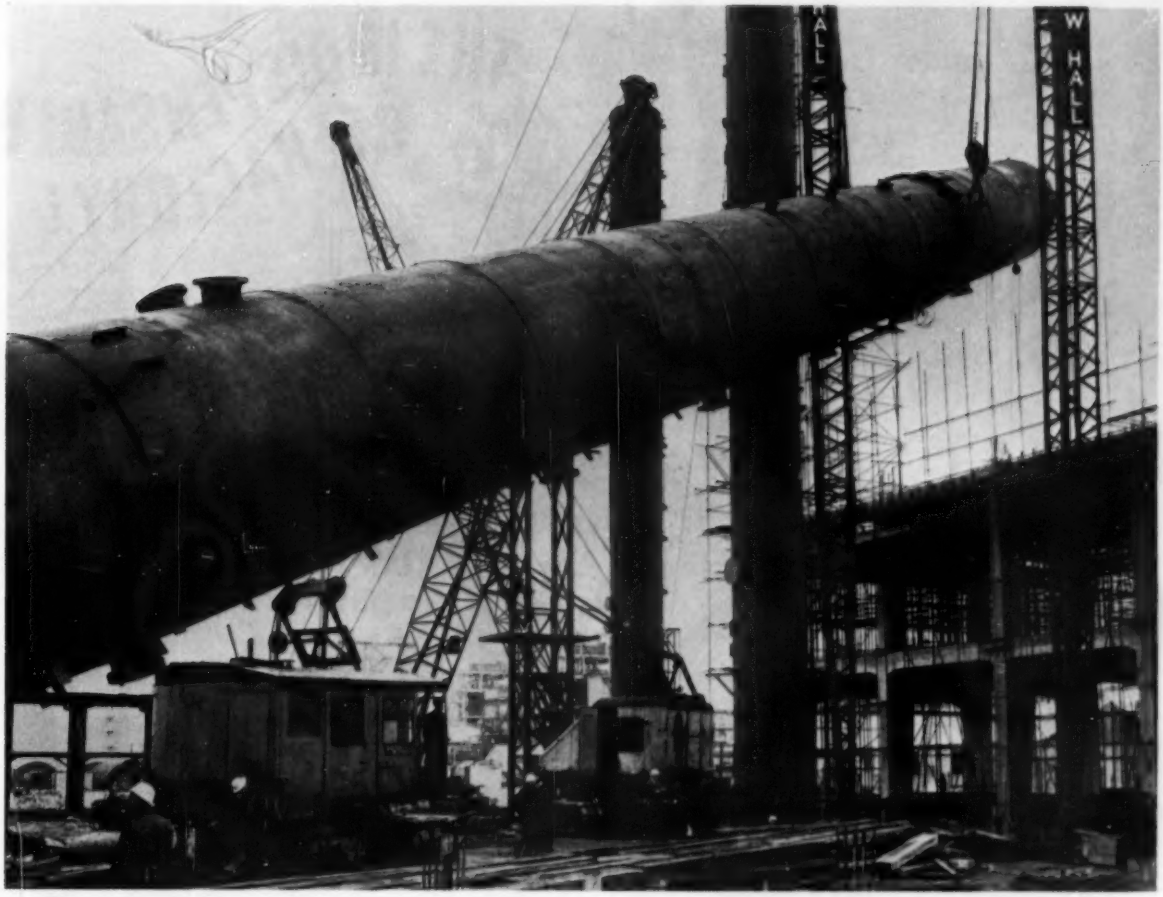
OIL REFINERY ENGINEERS

ESTD. 1848

MATTHEW HALL

MATTHEW HALL HOUSE, DORSET SQUARE, LONDON, N.W.1

Glasgow Manchester Bristol Belfast Dublin Johannesburg Germiston Durban
Cape Town Welkom Lagos Bulawayo Salisbury (Central Africa) West Indies



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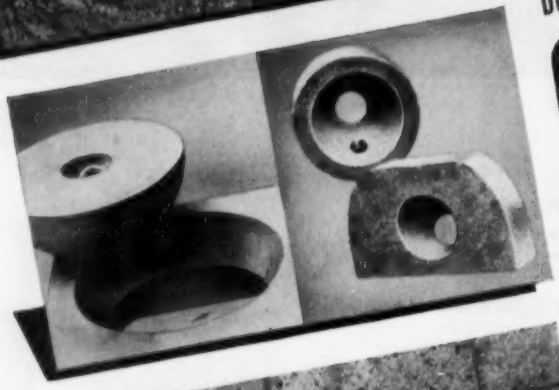

DURAX No 2

REFRACTORY CONCRETE

For casting in situ and making special shapes. Supplied dry. Special characteristics include—rapid setting as hard as firebrick: pours into position: no permanent volume change: little tendency to spall. Maximum service temperature 1300°C.

DURAX No 3

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A cement designed for application with a pneumatic gun. Alternatively it may be plastered into position. Durax No. 5 has little rebound loss when applied by gun to Catalytic Regenerators and forms a dense tough lining with a maximum service temperature of 1300°C.

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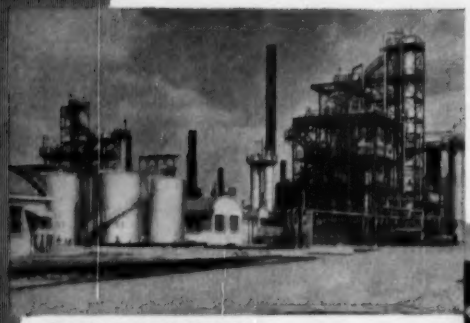

General view of crude, visbreaking, desulphurising, recovery and stabilisation units.

Graphic type panels are installed on both sides of control room with operator desk panels in centre. Crude and visbreaker unit panel is illustrated.

General view of Refinery with Mantova in background.

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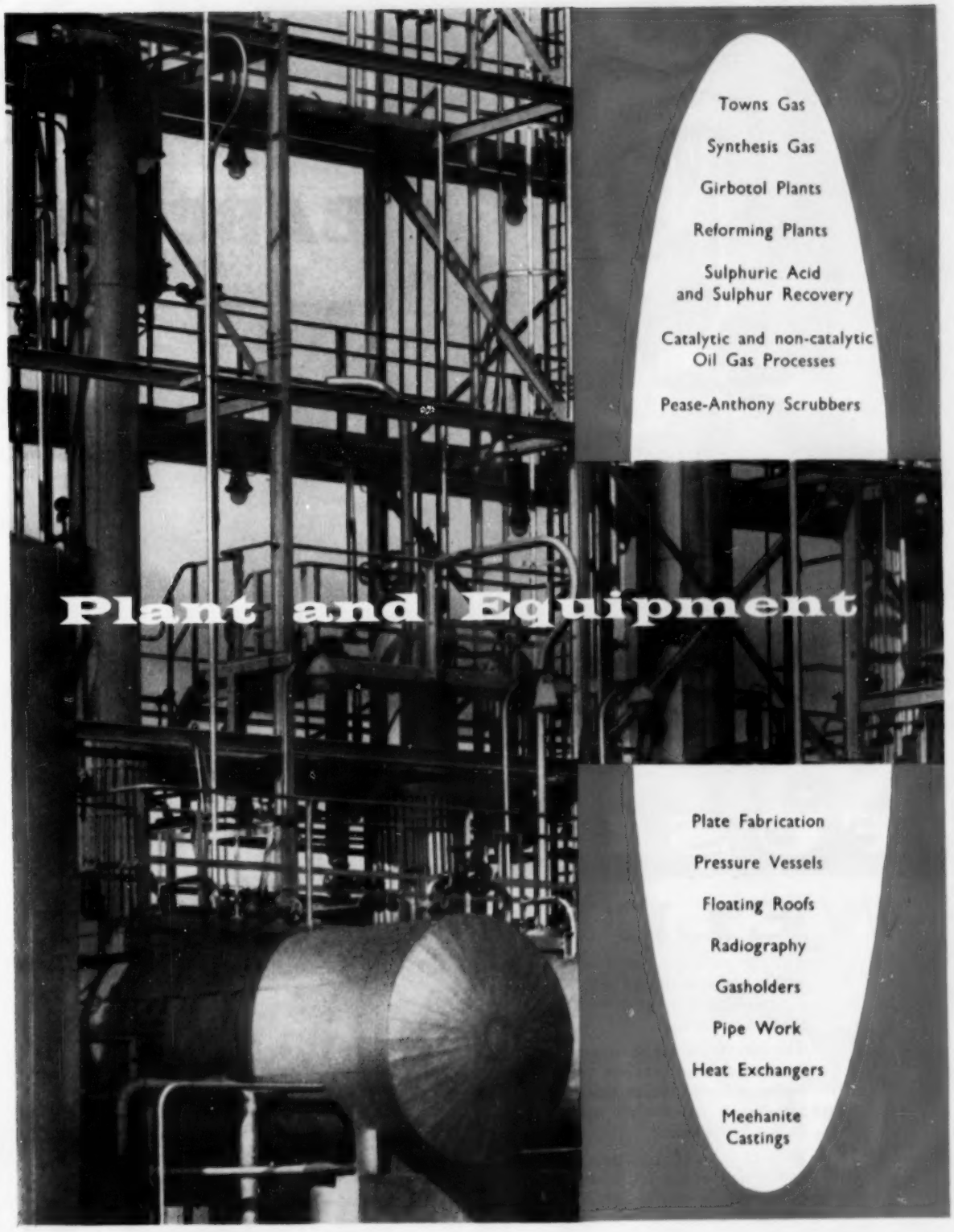

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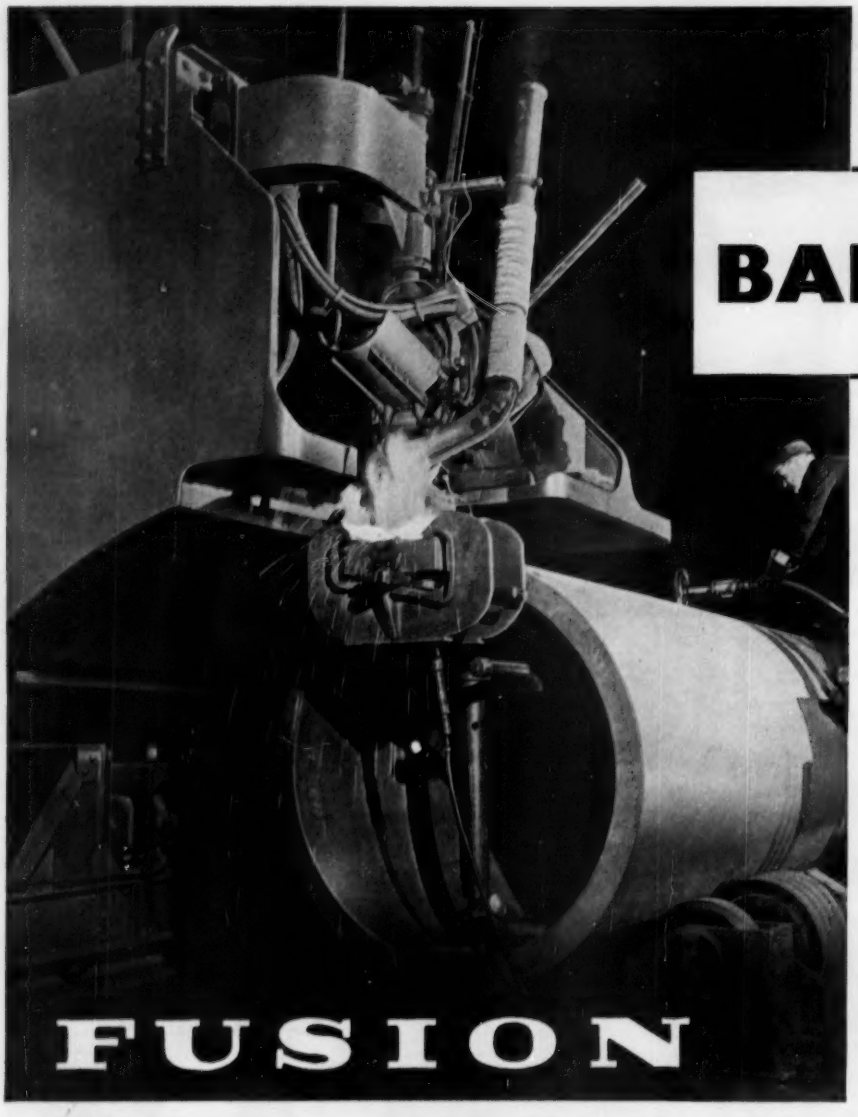

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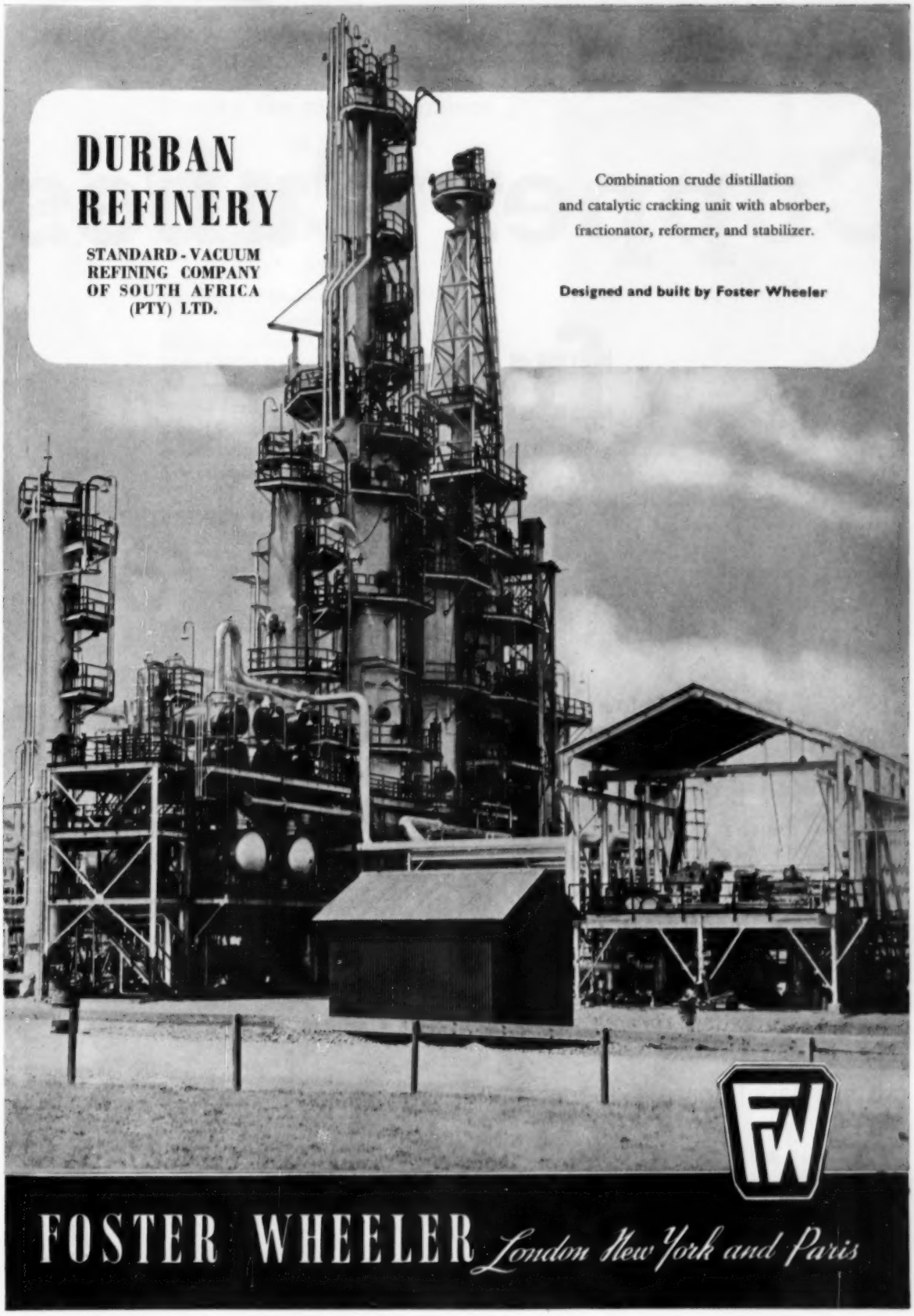
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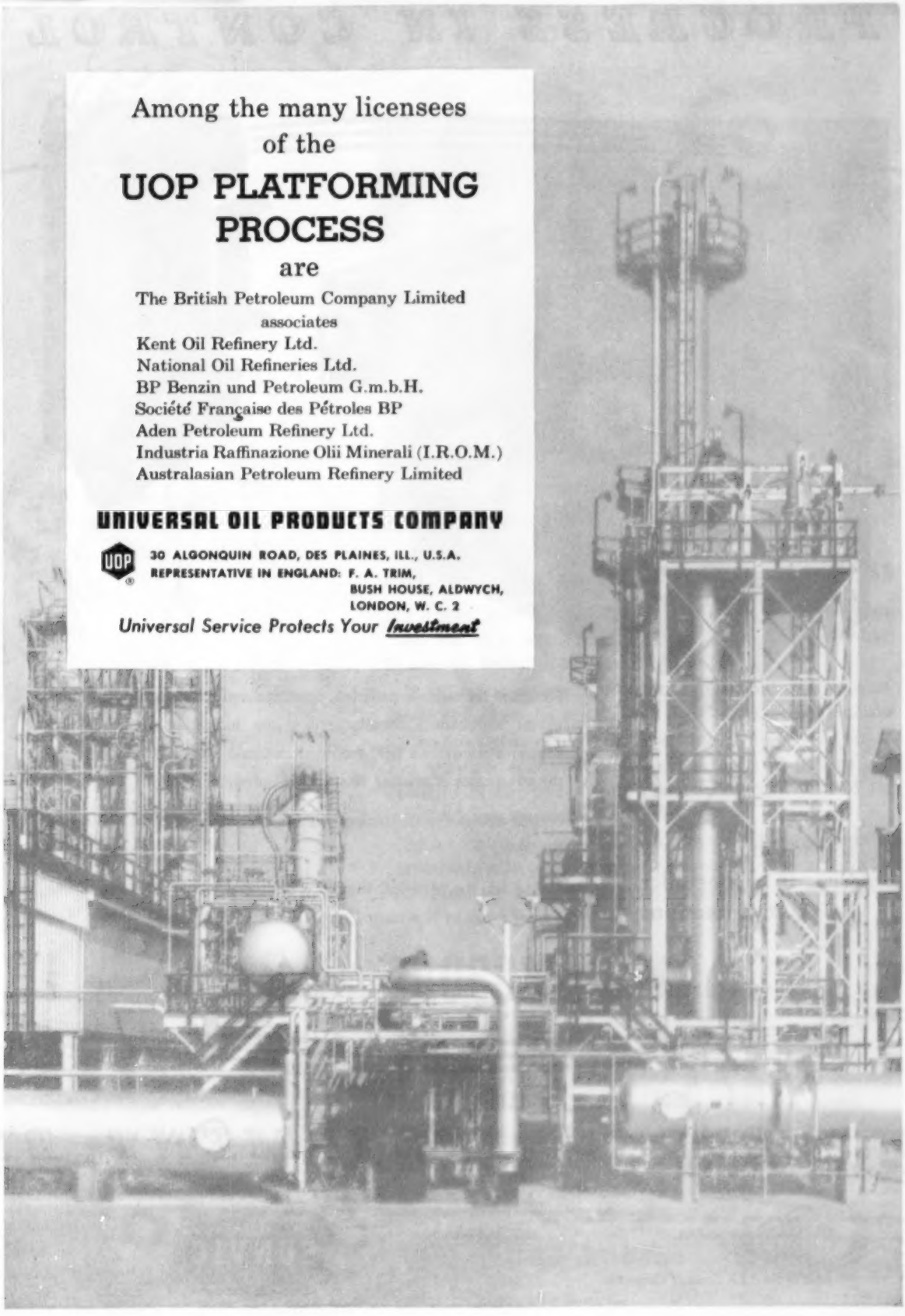

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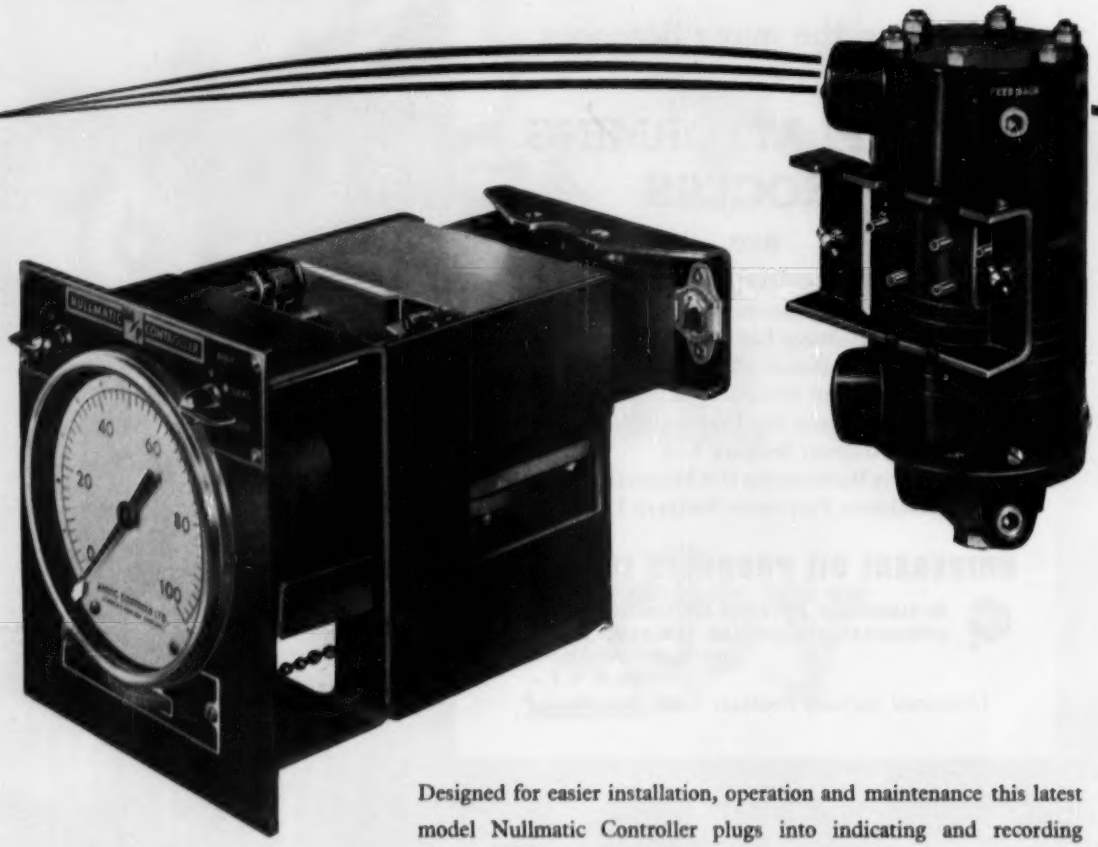

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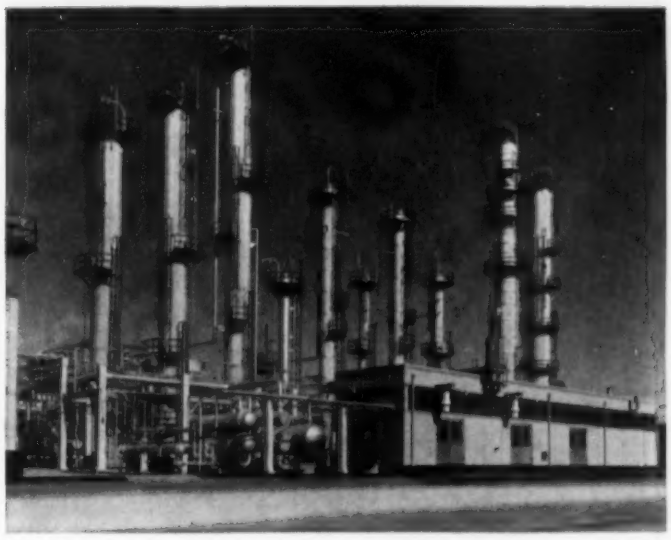

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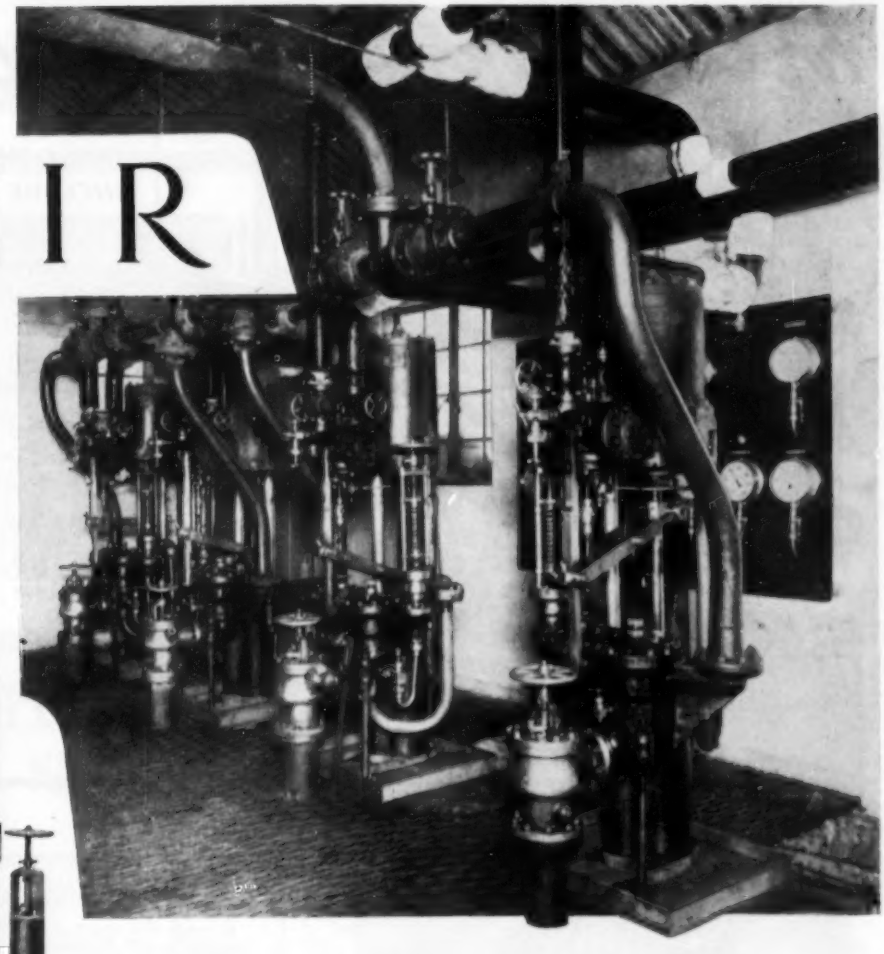

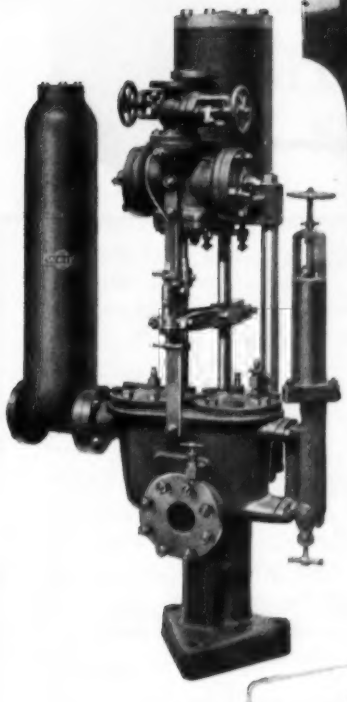

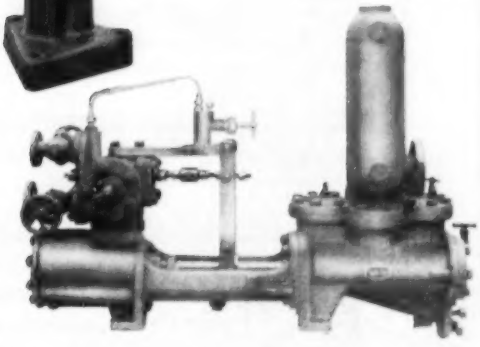

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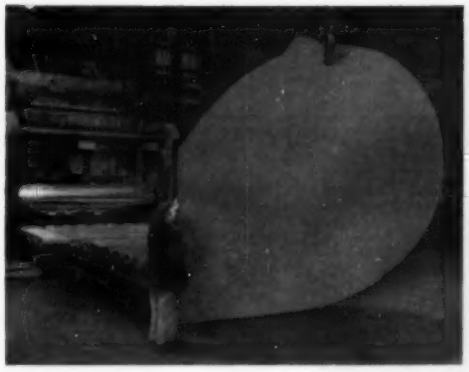

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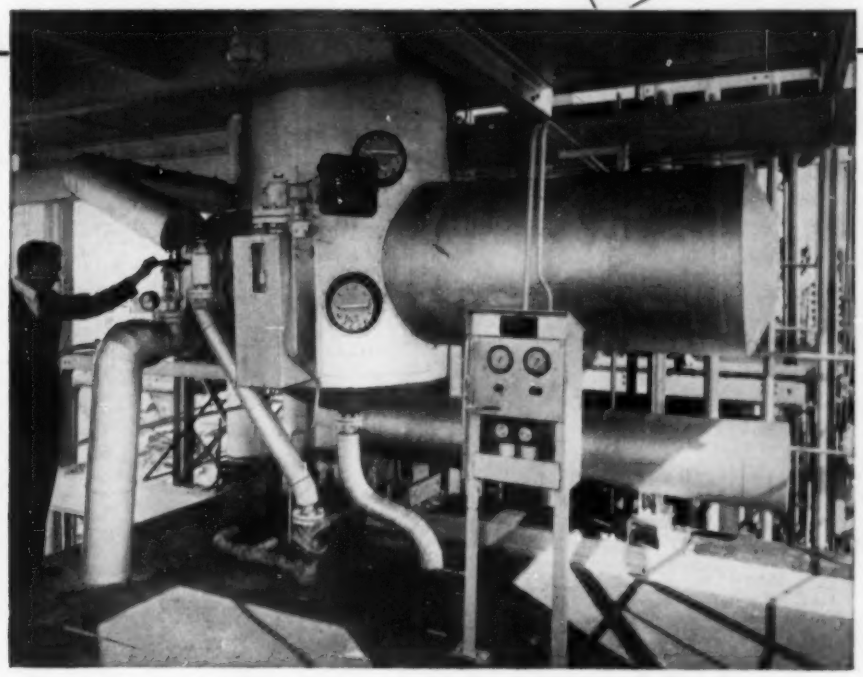

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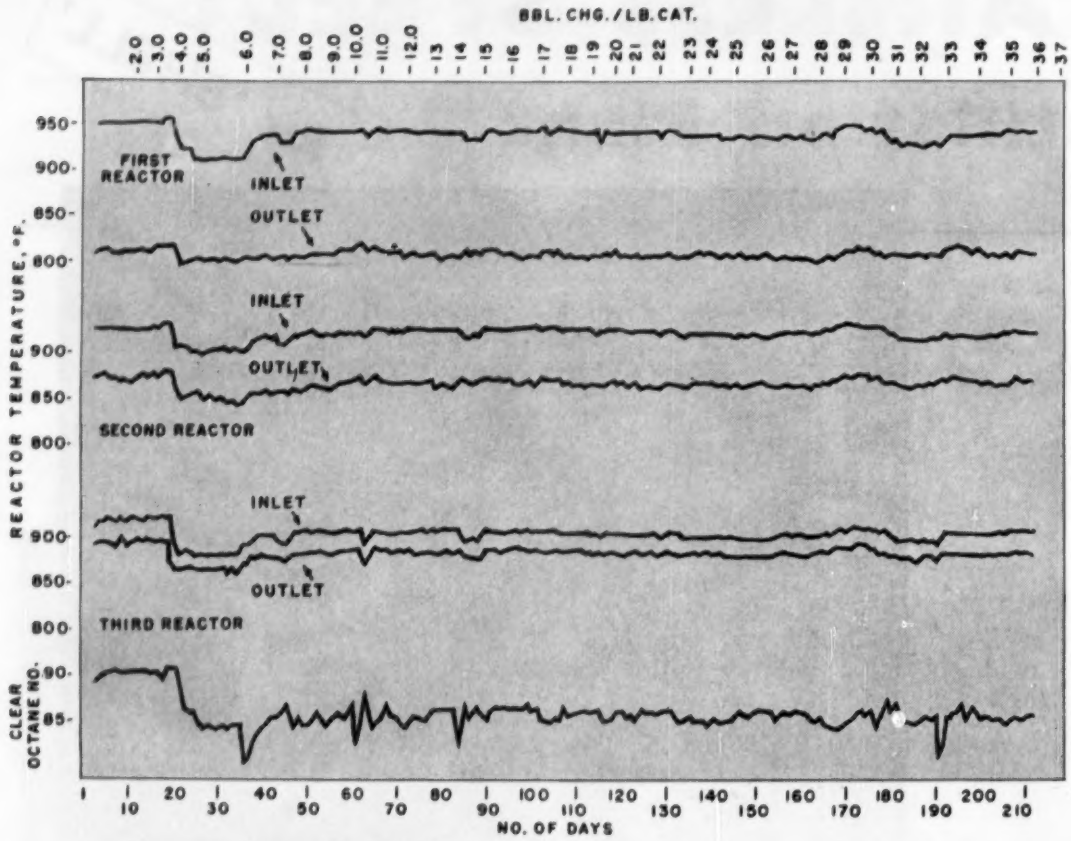

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- ★ **A Rich Source of Hydrogen**

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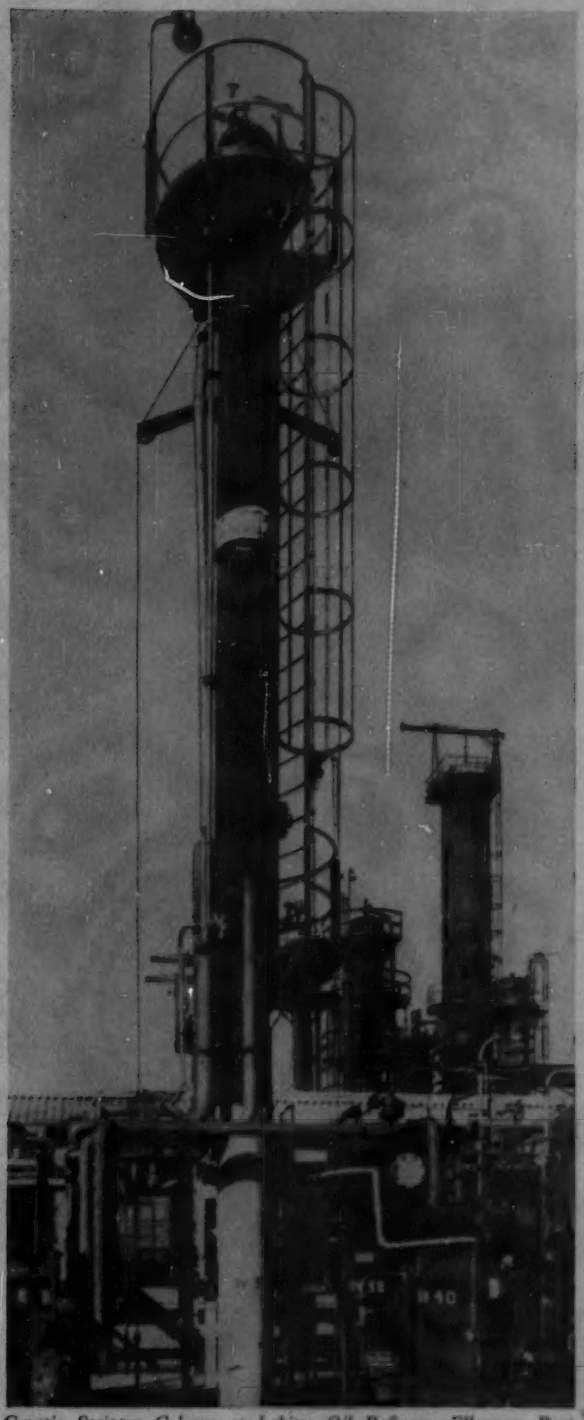

Caustic Stripper Column at Lobitos Oil Refinery, Ellesmere Port, manufactured by Metal Propellers Ltd. Column, pipe lines, tees and heat exchanger parts in Monel.

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Gasoline distillates often contain small amounts of mercaptans, compounds analogous to alcohols but containing sulphur in place of oxygen. Mercaptans are malodorous, have adverse effects on octane ratings, and are corrosive in certain conditions.

In the Unisol Process, developed by Universal Oil Products Company, mercaptans are removed by contacting the distillate with methanol and caustic soda in a liquid-liquid counter-current extraction system. Treated gasoline is withdrawn from one end of the system and the mercaptan-containing caustic methanol solution from the other. The caustic is recovered by stripping free of methanol and mercaptans using live steam in a Monel column packed with carbon Raschig rings. The methanol and mercaptans are obtained as overhead products in this column, both the methanol and caustic being available for further service.

The Ellesmere Port refinery of Lobitos Oilfields Ltd., has a caustic stripper of this nature made entirely of Monel plate. Pipe lines, tees and heat exchanger parts are also of Monel. Monel is resistant to caustic at temperatures and concentrations which would cause damage to steel equipment by caustic embrittlement.

Corrosion test results and service records point to the suitability of Monel, as well as nickel and Inconel for use in resisting caustic corrosion.

This instance is just one of the many where Monel is used in countering corrosion. Our publication "Monel & 'K' Monel, Properties & Applications" and detailed information on other Wiggin nickel alloys will be sent without charge, on request. Your specific problem will gladly be dealt with by our Technical Service.

'Monel' and 'Inconel' are Registered Trade Marks.

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it's plain to see... the Kenyon organisation embraces many interests. They offer the most complete range of thermal insulation materials for every type of steam consumption and chemical process, including erection services anywhere in the world.

For builders and architects they produce a comprehensive variety of insulation materials for all requirements. Sheet metal work of all descriptions is another of their large scale activities. The textile companies in the Kenyon organisation produce ropes, cords and narrow fabrics in natural and synthetic fibres.

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